User Manual

FieldForce TRAX

Attitude & Heading Reference System (AHRS)

PNI SENSOR CORPORATION

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1 Copyright & Warranty Information

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If any Product furnished hereunder fails to conform to the above warranty, OEM's sole and exclusive remedy and PNI's sole and exclusive liability will be, at PNI's option, to repair, replace, or credit OEM's account with an amount equal to the price paid for any such Product which fails during the applicable warranty period provided that (i) OEM promptly notifies PNI in writing that such Product is defective and furnishes an explanation of the deficiency; (ii) such Product is returned to PNI's service facility at OEM's risk and expense; and (iii) PNI is satisfied that claimed deficiencies exist and were not caused by accident, misuse, neglect, alteration, repair, improper installation, or improper testing. If a Product is defective, transportation charges for the return of the Product to OEM within the United States and Canada will be paid by PNI. For all other locations, the warranty excludes all costs of shipping, customs clearance, and other related charges. PNI will have a reasonable time to make repairs or to replace the Product or to credit OEM's account. PNI warrants any such repaired or replacement Product to be free from defects in material and workmanship on the same terms as the Product originally purchased.

Except for the breach of warranty remedies set forth herein, or for personal injury, PNI shall have no liability for any indirect or speculative damages (including, but not limited to, consequential, incidental, punitive and special damages) relating to the use of or inability to use this Product, whether arising out of contract, negligence, tort, or under any warranty theory, or for infringement of any other party's intellectual property rights, irrespective of whether PNI had advance notice of the possibility of any such damages, including, but not limited to, loss of use, revenue or profit. In no event shall PNI's total liability for all claims regarding a Product exceed the price paid for the Product. PNI neither assumes nor authorizes any person to assume for it any other liabilities.

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2 Introduction

Thank you for purchasing PNI Sensor Corporation's Trax attitude & heading reference system (AHRS). The Trax employs a proprietary Kalman filtering algorithm that intelligently fuses PNI's patented Reference Magnetic Sensors with a 3-axis gyroscope and 3-axis accelerometer. The result is an orientation device that provides accurate heading information under a wide variety of conditions, including its ability to overcome errors normally caused by erratic motion and/or changes in the local magnetic field. The advanced features of the Trax make it ideal for a variety of applications, including:

- Unmanned Ground Vehicles (UGV) – Robots and Unmanned Conversions
- Unmanned Underwater Vehicles (UUV) – Autonomous Gliders and ROV's

We're sure the Trax will help you to achieve the greatest performance from your system. Thank you for selecting the Trax.

3 Specifications

3.1 Characteristics & Requirements

Table 3-1: Performance Specifications in AHRS Mode[1]

Parameter			Value
Heading	Accuracy[2]		2.0° rms
	Resolution		0.1°
Attitude	Range	Pitch	± 90°
		Roll	± 180°
	Accuracy		2.0° rms
	Resolution		0.01°
Power Consumption	Average Current Draw @ Maximum Sample Rate		55 mA
	Current Draw During Application of External Power		See Figure 3-1

Table 3-2: Performance Specifications in Compass Mode[1]

Parameter			Value
Heading	Static Accuracy[3]		0.3° rms
	Resolution		0.1°
	Repeatability		0.05° rms
Attitude	Range	Pitch	± 90°
		Roll	± 180°
	Static Accuracy		0.2° rms
	Resolution		0.01°
	Repeatability		0.05° rms
Power Consumption	Average Current Draw @ Maximum Sample Rate		28 mA
	Sleep Mode Current Draw		0.5 mA

Table 3-3: I/O Characteristics

Parameter	Value
Supply Voltage	3.6 to 5 VDC
Communication Interface	RS232 UART & USB
Communication Protocol	PNI Binary
Communication Rate[4]	2400 to 921,600 baud
Maximum Data Output Rate	≈30 samples/sec

Table 3-4: Environmental Requirements

Parameter	Value
Operating Temperature[5]	-40C to +85C
Storage Temperature	-40C to +85C

Table 3-5: Mechanical Characteristics

Parameter		Value
Dimensions (*l* x *w* x *h*)	Trax Enclosed	6.4 x 5.9 x 2.3 cm
	Trax PCA	3.5 x 4.3 x 1.3 cm
Weight	Trax Enclosed	75 gm
	Trax PCA	7 gm
Connector	Trax Enclosed	7 pin ODU, pn K20L0C-P07LCC0-520S
	Trax PCA	9-pin Molex, pn 53780-0970

Footnotes to Tables:

1. Specifications are typical unless otherwise noted, and subject to change.
2. Assumes heading status is "1". See Section 6.6 or Section 7.5.3
3. Assumes Trax is motionless and the local magnetic field is clean relative to user calibration.
4. The Trax can operate up to 921,600 baud, but native RS232 is limited to 115,200 baud.
5. To meet performance specifications across this range, recalibration will be necessary as the temperature varies.

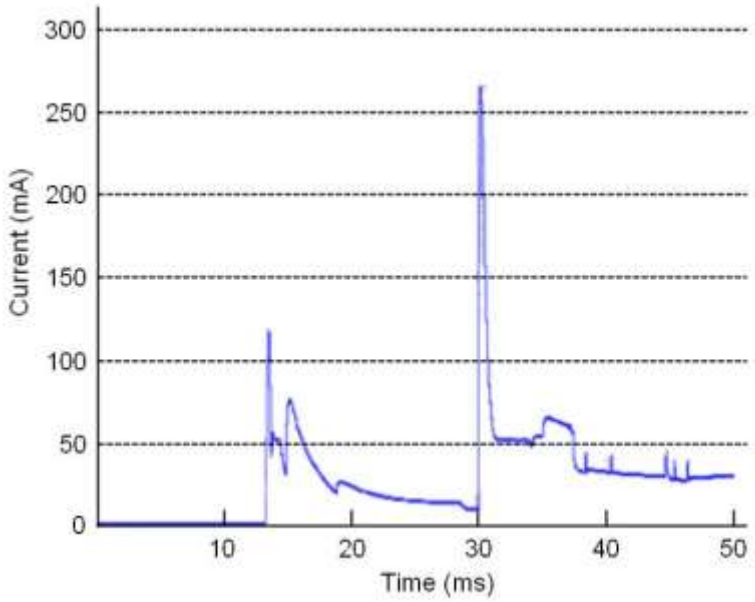


Figure 3-1: Typical Current Drawing During Application of External Power

3.2 Mechanical Drawings

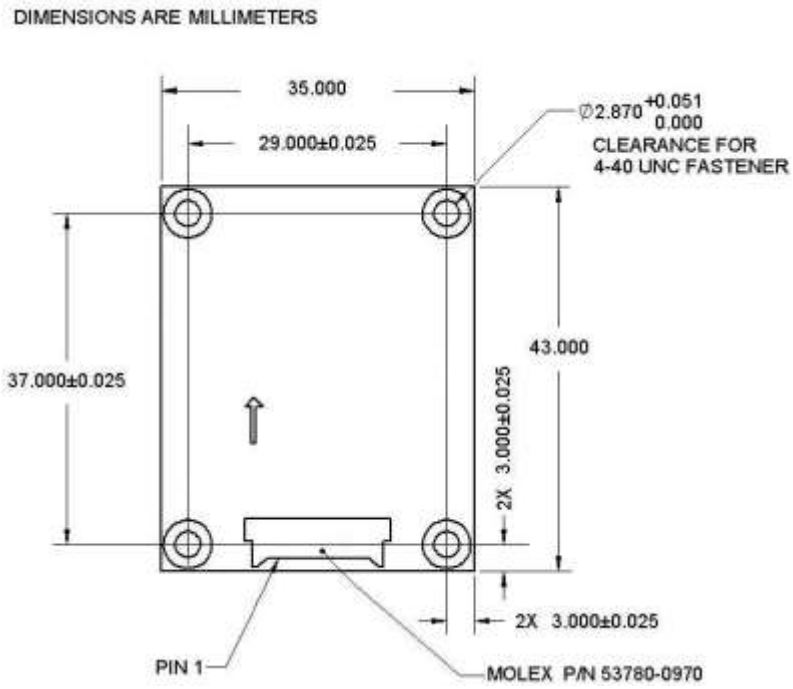


Figure 3-2: Trax PCA Mechanical Drawing

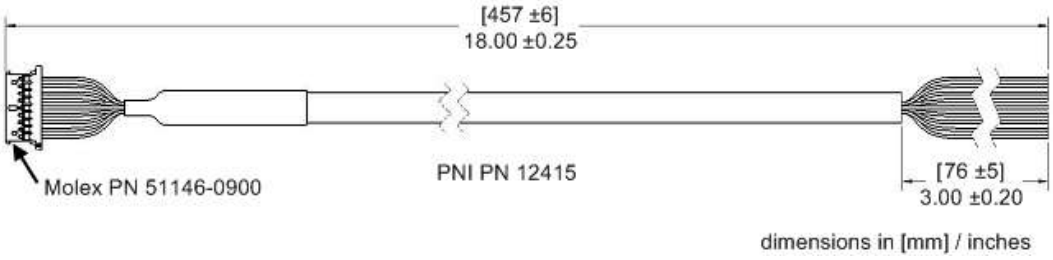


Figure 3-3: PNI Pigtailed Molex Cable Drawing

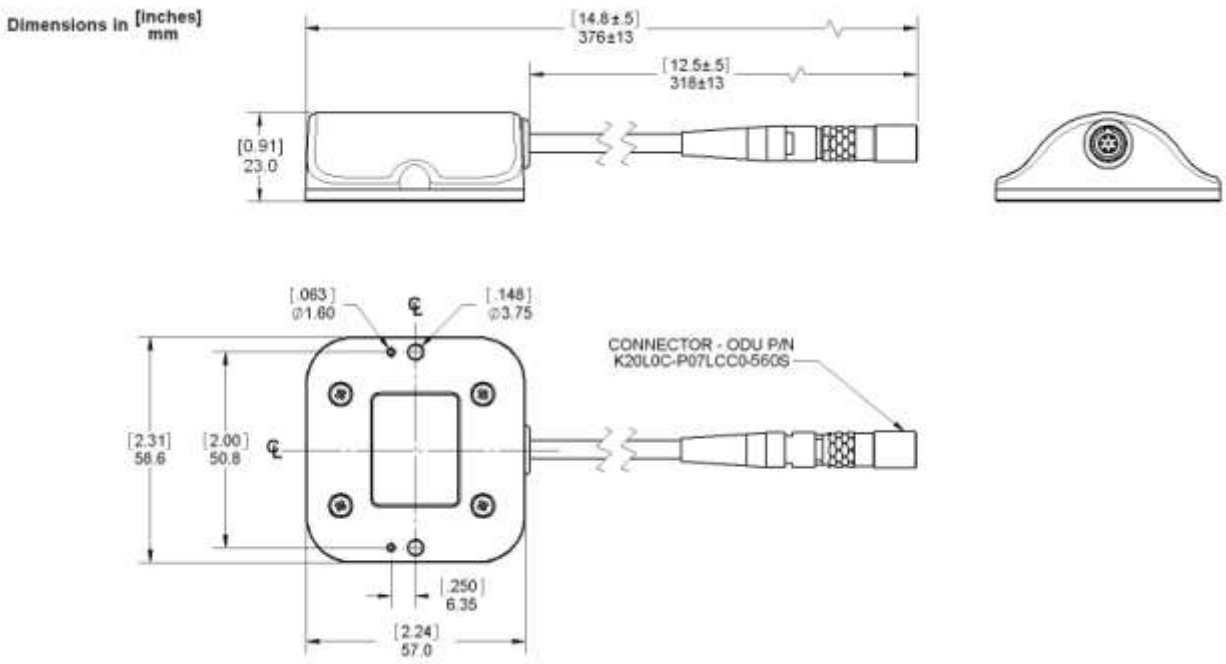


Figure 3-4: Trax Enclosed Mechanical Drawing

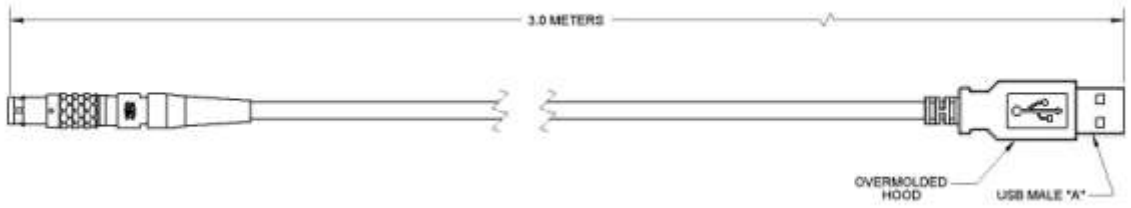


Figure 3-5: Trax USB Cable Drawing

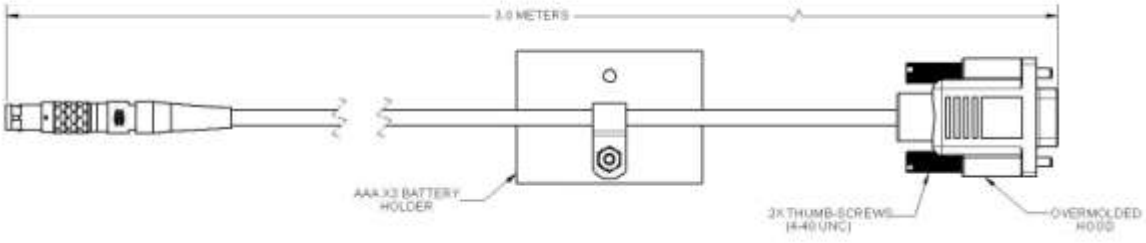


Figure 3-6: Trax RS232 Cable Drawing

4 Set-Up

This section describes how to configure the Trax in your host system. To install the Trax into your system, follow these steps:

- Make electrical connections to the Trax.
- Evaluate the Trax using the Trax Studio program, or a binary terminal emulation program, such as RealTerm or Tera Term, to ensure the Trax is working properly.
- Choose a mounting location.
- Mechanically mount the Trax in the host system.
- Perform a user calibration.

4.1 Electrical Connections

The enclosed version of Trax incorporates a pigtailed 7 pin ODU connector, part number K20L0C-P07LCC0-560S, which mates with ODU part S20L0C-T07MCC0-560S or equivalent. The Trax PCA incorporates a 9 pin Molex connector, part number 53780-0970, which mates with Molex part 51146-0900 or equivalent. The pin-out for both is given below in Table 4-1.

Table 4-1: Trax Pin Descriptions

Pin #[1]	Trax Enclosed	Trax PCA	
	Pigtailed 7 Pin Connector*	9 Pin Molex Connector	PNI Cable Wire Color
1	USB D+	Ground	Black
2	RS232 +5 VDC	USB +5 VDC	Gray
3	RS232 Tx	Ground	Green
4	RS232 Rx	Not Connected	Orange
5	USB + 5 VDC	USB D–	Violet
6	USB D– A	USB D+	Brown
7	Ground	RS232 Tx	Yellow
8		RS232 Rx	Blue
9		RS232 +5 VDC	Red

Footnote:

1. For the Trax Enclosed, pin #1 is the first pin to the left of the key, and numbering runs counter-clockwise from pin #1, with pin #7 in the middle. For the Trax PCA, pin #1 is indicated on Figure 3-2.

After making the electrical connections, it is a good idea to perform some simple tests to ensure the Trax is working as expected. See Section 6 for how to operate the Trax with Trax Studio or Section 7 for how to operate the Trax using PNI's binary protocol.

4.2 Installation Location

The Trax's wide dynamic range and sophisticated algorithms allow it to operate in many environments. For optimal performance however, you should mount the Trax with the following considerations in mind:

4.2.1 Operate within the Trax's dynamic range

The Trax can be field calibrated to correct for static magnetic fields created by the host system. However, each axis of the Trax has a calibrated dynamic range of ±125 μT. If the total field exceeds this value for any axis, the Trax may not perform to specification. When mounting the Trax, consider the effect of any sources of magnetic fields in the host environment that, when added to Earth's field, may take the Trax out of its dynamic range. For example, large masses of ferrous metals such as transformers and vehicle chassis, large electric currents, permanent magnets such as electric motors, and so on.

4.2.2 Locate away from changing magnetic fields

While the Trax can compensate for transient changes in the local magnetic field, it is good design practice to keep the Trax away from sources of local magnetic distortion that knowingly will change with time; such as electrical equipment that will be turned on and off, or ferrous bodies that will move.

4.2.3 Mount in a physically stable location

Choose a location that is isolated from persistent vibration or other dynamic motion. The Trax can provide accurate headings while experiencing intermittent dynamic motion, such as vibration or quick heading changes. But if this is persistent the Trax will have difficulty holding an accurate heading over extended periods of time.

4.3 Mechanical Mounting

The Trax is factory calibrated with respect to its mounting holes. It must be aligned within the host system with respect to these mounting holes. Ensure any stand-offs or screws used to mount the Trax are non-magnetic. Refer to Section 3.2 for dimensions, hole locations, and the reference frame orientation.

4.3.1 Pitch and Roll Convention

The Trax utilizes Euler angles as the primary method for providing orientation data, although quaternions outputs also are available. The Euler angles are the common method used for aircraft orientation, where the outputs are heading, pitch and roll. When

using Euler angles in aviation, roll is defined as the angle rotated around an axis through the center of the fuselage, while pitch is rotation around an axis through the center of the wings. These rotations are dependent on each other since the axes of rotation move with the plane.

As shown in Figure 4-1, for the Trax a positive pitch is when the front edge of the board is rotated upward and a positive roll is when the right edge of the board is rotated downward. The order of rotation is given as heading, pitch, and then roll.

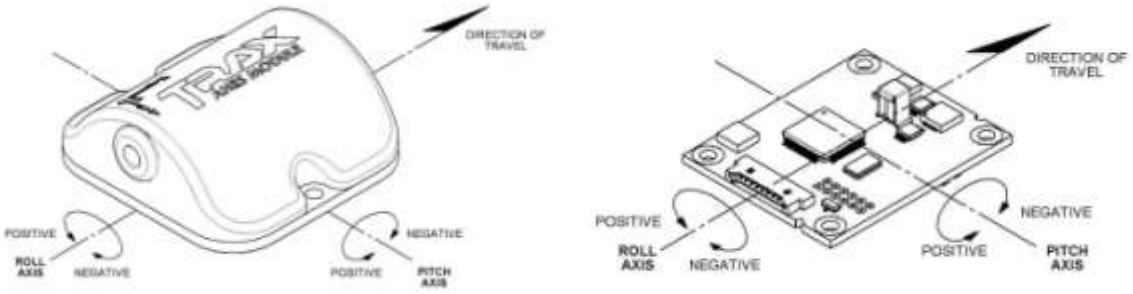


Figure 4-1: Positive & Negative Roll and Pitch Definition

4.3.2 Mounting Orientation

The Trax can be mounted in 16 different orientations, as shown for the enclosed version of the Trax in Figure 4-2. All reference points are based on the silk-screened arrow on the cover of the enclosed version of the Trax, or on top side of the Trax PCA board. The orientation should be programmed in the Trax using the Configuration Tab in Trax Studio or using the kSetConfig command and the kMountingRef setting in the PNI Protocol, as described in Section 7.4.2. The default orientation is "STD 0°".

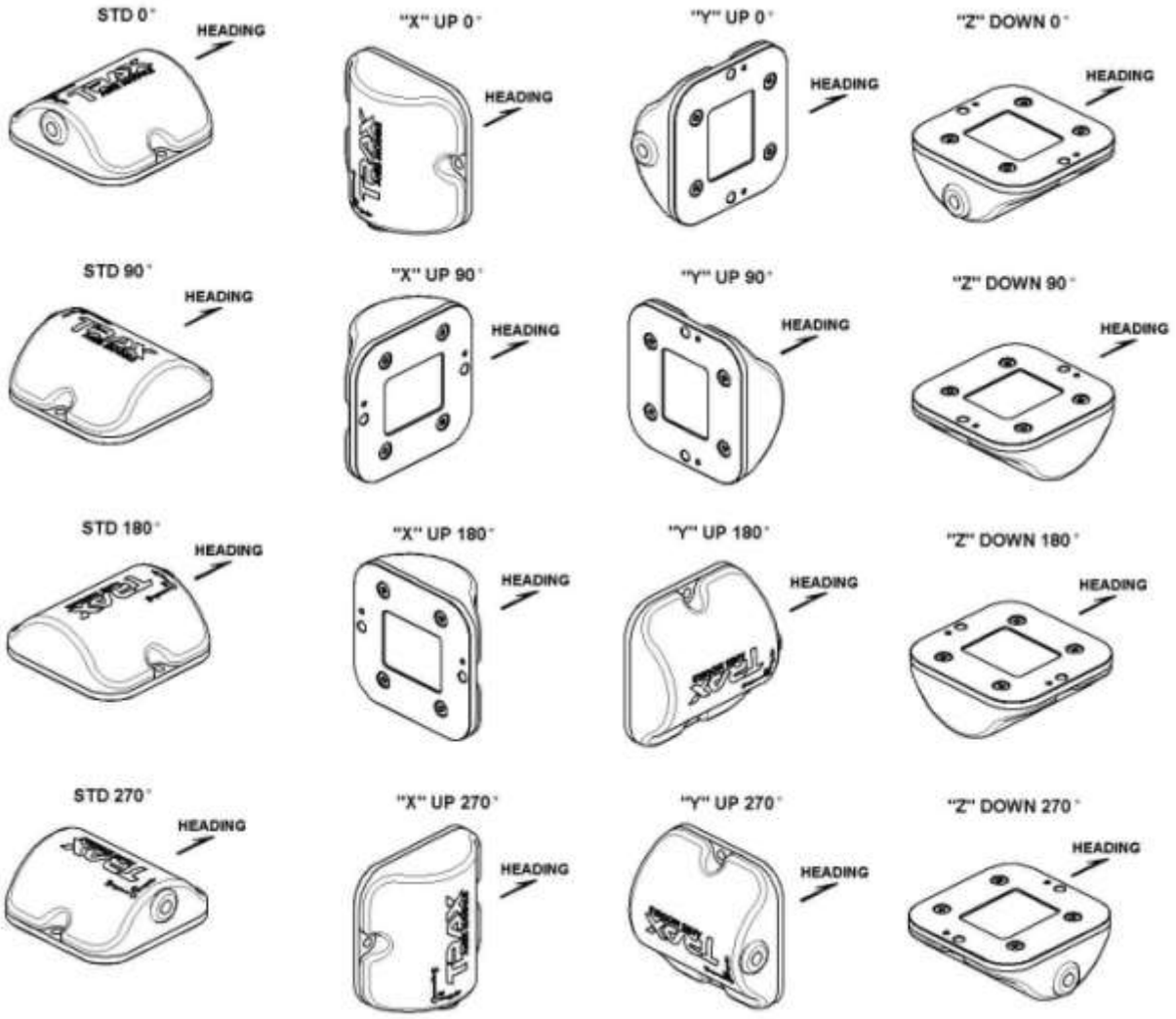


Figure 4-2: Trax Enclosed Mounting Orientations

5 Calibration

To optimize the performance of the Trax such that it performs to specification it is necessary to properly calibrate both the magnetic sensors and the accelerometers in the device.

The magnetic sensors in the Trax are calibrated at PNI's factory in a magnetically controlled environment. However sources of magnetic distortion positioned near the Trax in the user's system will distort Earth's magnetic field and should be compensated for in the host system with a user calibration. Examples of such sources include ferrous metals and alloys (ex. iron, nickel, steel, etc.), batteries, audio speakers, current-carrying wires, and electric motors. Compensation is accomplished by mounting the Trax in the host system and performing a user calibration. It is expected the sources of magnetic distortion remain fixed relative to the Trax's position within the host system. By performing a calibration, the Trax identifies the local sources of magnetic distortion and negates their effects from the overall reading to provide an accurate heading.

As with the magnetic sensors, the accelerometers in the Trax are calibrated at PNI's factory. But the accelerometers gradually change over time, and the user either will need to periodically perform a user accelerometer calibration or return the unit to PNI for recalibration. As a rule-of-thumb, the accelerometers should be recalibrated every 6 to 12 months. Unlike a magnetic calibration, the accelerometers may be calibrated outside the host system. Accelerometer calibration is more sensitive to noise or hand jitter than magnetic calibration, especially for subsequent use at high tilt angles. Because of this, a stabilized fixture is suggested for accelerometer calibration, although resting the unit against a stable surface often is sufficient.

Key Points:

- User calibration is required for the Trax to perform optimally and meet specification.
- Magnetometer calibration:
    - Requires incorporating the Trax into the user's host system such that the magnetic components of the user's system can be compensated for.
    - Allows for 4 different methods of calibration. Full Range Calibration provides the highest heading accuracy, but requires ≥45° of pitch during calibration. 2D and Limited Tilt Calibration allow for good calibration when the range of allowable motion is limited. Hard Iron Only Calibration updates the hard-iron compensation coefficients with a relatively easy procedure.
- Accelerometer calibration requires rotating the Trax through a full sphere of coverage, but the Trax does not need to be incorporated into the user's system during calibration.

5.1 Magnetic Calibration

Two fundamental types of magnetic distortion exist: hard iron and soft iron. These are discussed in the following paragraphs, plus a discussion on how temperature effects magnetic fields and other considerations. For more information on magnetic distortion and calibration, see PNI's white paper "Local Magnetic Distortion Effects on 3-Axis Compassing" at PNI's website (http://www.pnicorp.com/technology/papers).

Hard Iron Effects

Hard iron distortions are caused by permanent magnets and magnetized steel or iron objects within close proximity to the sensors. This type of distortion remains constant and in a fixed location relative to the sensors for all heading orientations. Hard-iron distortions add a constant magnitude field component along each axis of sensor output.

Soft Iron Effects

Soft-iron distortions are the result of interactions between the Earth's magnetic field and any magnetically "soft" material within close proximity to the sensors. In technical terms, soft materials have a high permeability. The permeability of a given material is a measure of how well it serves as a path for magnetic lines of force, relative to air, which has an assigned permeability of one. Unlike hard-iron distortion, soft-iron distortion changes as the host system's orientation changes, making it more difficult to compensate.

Temperature Effects

While the hard iron and soft iron distortions of a given component in a system may remain quite stable over time, normally this distortion signature will change over temperature. Therefore, no matter how stable a compass is over temperature, it is usually necessary to recalibrate as the temperature changes since the magnetic distortion signature of the host system will change over temperature. One way the Trax helps with this issue is by allowing the user to save up to 8 sets of calibration coefficients, so that as the temperature changes a magnetic calibration coefficient set matching the new temperature can be used in the Trax.

Other Considerations

The Trax measures the total magnetic field within its vicinity, and this is a combination of Earth's magnetic field and local magnetic sources. The Trax can compensate for local static magnetic sources. However, a magnetic source which is not static, such as a motor which turns on/off, can create errors and it is not possible to compensate for such a dynamic nature. In such cases, keeping the Trax away from dynamic magnetic fields is recommended, or taking measurements only when the

state of the magnetic field is know. For example, only take measurements when a nearby motor is turned off.

The main objective of a magnetic user calibration is to compensate for hard iron and soft iron distortions to the magnetic field caused by components within the user's host system. To that end, the Trax needs to be mounted within the host system and the entire host system needs to be moved as a single unit during a user calibration. The Trax allows the user to perform a calibration only in a 2D plane or with limited tilt, but provides the greatest accuracy if the user can rotate through a full sphere.

The following subsections provide instructions for performing a magnetic calibration of a Trax system. Calibration may be performed using Trax Studio or using the PNI binary protocol, and up to 8 sets of calibration coefficients may be saved. The recommended calibration patterns described in the following sub-sections provide a good distribution of sample points. Also, PNI recommends the location of the Trax remain fairly constant while only the orientation is changed.

Table 5-1: Magnetic Calibration Mode Summary

Calibration Mode	Static Accuracy in Compass Mode	Tilt Range during Cal	# of Samples in Recommended Cal Pattern	Allowable Range of # of Samples
Full Range	0.3° rms	>±45°	12	10 – 18
2D Calibration	<2°	<±5°	12	10 – 18
Limited Tilt Range	<2° over 2x tilt range	±5° to ±45°	12	10 – 18
Hard Iron Only	Restores prior accuracy	>±3°	6	4 - 18

Before proceeding with a calibration, ensure the Trax is properly installed in the host system. The device should be installed as discussed in Section 4, and the software should be properly configured with respect to the mounting orientation, Endianness, north reference, etc.

Section 6.5 outlines how to perform a calibration using Trax Studio, while Section 7.6.2 provides a step-by-step example of how to perform a calibration using the PNI protocol.

5.1.1 Full Range Calibration

A Full Range Calibration is appropriate when the Trax can be tilted ±45° or more. This method compensates for hard and soft iron effects in three dimensions, and allows for the highest accuracy readings.

The recommended 12 point calibration pattern is a series of 3 circles of evenly spaced points, as illustrated in Figure 5-1 and listed in Table 5-2. The pitch used in the second and third circles of the calibration should at least match the maximum and minimum pitch the device is expected to encounter in use.

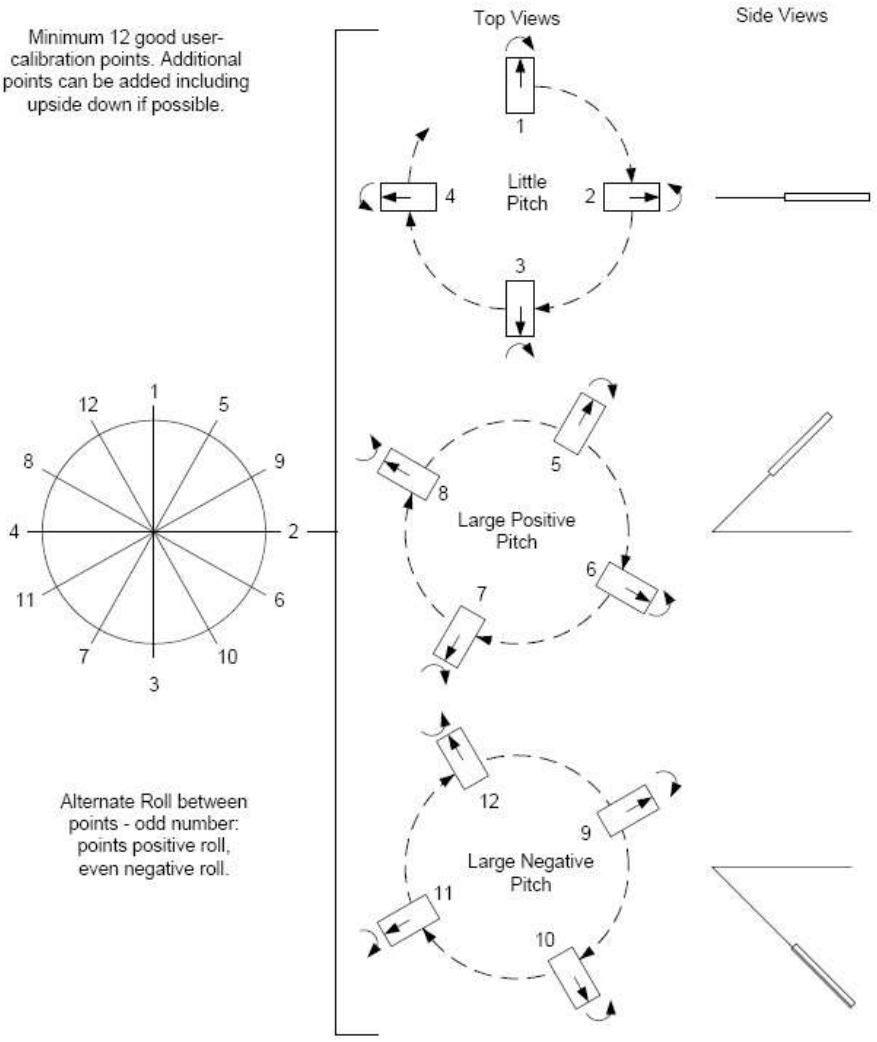

Minimum 12 good user-calibration points. Additional points can be added including upside down if possible.
Top Views
Side Views
Little Pitch
Large Positive Pitch
Large Negative Pitch
Alternate Roll between points - odd number: points positive roll, even negative roll.

Figure 5-1: 12 Point Full Range Calibration

Note: *While Figure 5-1 shows the location of the device changing, this is for illustration purposes and it is best for the location of the device to remain constant while only the orientation is changed.*

Table 5-2: 12 Point Full Range Calibration Pattern

Sample #		Yaw[1]	Pitch	Roll
First Circle				
	1	0°	±5°	30° to 40°
	2	90°	±5°	-30° to -40°
	3	180°	±5°	30° to 40°
	4	270°	±5°	-30° to -40°
Second Circle				
	5	30°	> +45°	30° to 40°
	6	120°	> +45°	-30° to -40°
	7	210°	> +45°	30° to 40°
	8	300°	> +45°	-30° to -40°
Third Circle				
	9	60°	< -45°	30° to 40°
	10	150°	< -45°	-30° to -40°
	11	240°	< -45°	30° to 40°
	12	330°	< -45°	-30° to -40°

Footnote:

1. Yaw listings are not absolute heading directions but rather relative heading referenced to the first sample.

5.1.2 2D Calibration

A 2D Calibration is intended for very low tilt operation (<5°) where calibrating the Trax with greater tilt is not practical.

This procedure calibrates for hard and soft iron effects in only two dimensions, and in general is effective for operation and calibration in the tilt range of -5° to +5°. The recommended 12 point calibration pattern is a circle of evenly spaced points, as given in Table 5-3.

Table 5-3: 12 Point 2D Calibration Pattern

Sample #	Yaw	Pitch[1]	Roll[1]
1	0°	0°	0°
2	30°	max. negative	max. negative
3	60°	0°	0°
4	90°	max. positive	max. positive
5	120°	0°	0°
6	150°	max. negative	max. negative
7	180°	0°	0°
8	210°	max. positive	max. positive
9	240°	0°	0°
10	270°	max. negative	max. negative
11	300°	0°	0°
12	330°	max. positive	max. positive

Footnote:

1. For best results, the tilt experienced during calibration should match that experienced in service. For example, if the Trax is restrained to a level plane in service, then calibration should be in a plane, where “max. positive” and “max. negative” are 0°.

5.1.3 Limited Tilt Range Calibration

A Limited Tilt Range Calibration is recommended when 45° of tilt isn’t feasible, but >5° of tilt is possible. It provides both hard iron and soft iron distortion correction. The recommended 12 point calibration pattern given below is a series of 3 circles of evenly spaced points, with as much tilt variation as expected during use.

Table 5-4: 12 Point Limited Tilt Calibration Pattern

Sample #	Yaw	Pitch	Roll
First Circle			
1	0°	0°	0°
2	90°	0°	0°
3	180°	0°	0°
6	270°	0°	0°
Second Circle			
7	45°	> +5°	> +5°
8	135°	> +5°	> +5°
11	225°	> +5°	> +5°
12	315°	> +5°	> +5°
Third Circle			
13	45°	< -5°	< -5°
14	135°	< -5°	< -5°
17	225°	< -5°	< -5°
18	315°	< -5°	< -5°

Note that a similar and acceptable alternative pattern would be to follow the recommended 12 point Full Range Calibration pattern, but substituting the >±45° of pitch with whatever pitch can be achieved and the ±10° to ±20° of roll with whatever roll can be achieved up to these limits. See Section 5.1.1 for more information.

5.1.4 Hard Iron Only Calibration

It is not uncommon for the hard-iron magnetic distortions around the Trax to change. Some reasons for this include significant temperature change or temperature shock to a system, as well as gradual aging of components. A Hard Iron Only Calibration allows for quick recalibration of the Trax for hard-iron effects, and generally is effective for operation and calibration in the tilt range of 3° or more (≥45° is preferred). The recommended 6 point calibration pattern given below is a circle of alternately tilted, evenly spaced points, with as much tilt as expected during use.

Table 5-5: 6 Point Hard Iron Only Calibration Pattern

Sample #	Yaw	Pitch[1]	Roll[1]
1	0°	max. negative	max. negative
2	60°	max. positive	max. positive
3	120°	max. negative	max. negative
4	180°	max. positive	max. positive
5	240°	max. negative	max. negative
6	300°	max. positive	max. positive

Footnote:

1. For best results, the tilt experienced during calibration should match that experienced in service. For example, if the Trax will be subject to ±45° of pitch and roll when in service, then "max negative" should be -45° and "max positive" should be +45°.

5.2 Accelerometer Calibration

The Trax uses MEMS accelerometers to measure the attitude (pitch and roll) of the compass. This data is output as pitch and roll data. Additionally, the accelerometer data is critical for establishing an accurate heading reading when the Trax is tilted, as discussed in the PNI white paper "Tilt-Induced Heading Error in a 2-Axis Compass", which can be found on PNI's web site (http://www.pnicorp.com/technology/papers).

As previously mentioned, PNI calibrates the accelerometers in its factory prior to shipment. But over time the bias and offset of the accelerometers will drift. For this reason PNI

recommends the accelerometers be recalibrated every 6 to 12 months. The user may return the Trax to PNI for accelerometer calibration, or the user may perform a user accelerometer calibration. The remainder of this section covers the user accelerometer calibration.

The requirements for a good user accelerometer calibration differ significantly from the requirements for a good magnetic calibration. Specifically, a good accelerometer calibration involves the Trax experiencing a wide range of pitch and roll values, preferably seeing both ±180° of pitch and ±180° of roll. Also, it is necessary that the Trax be held very still during an accelerometer calibration. If possible, PNI recommends using a fixture to hold the device during calibration, although resting the Trax on a hard surface normally is sufficient. On the other hand, the Trax does not need to be incorporated in the user's host system to perform a user accelerometer calibration, which significantly simplifies calibration when compared to magnetic calibration.

Figure 5-2 shows the two basic starting positions for the recommended 18-point calibration pattern. Starting with the Trax as shown on the left in Figure 5-2, rotate the device about its z axis such that it sits on each of its 4 edges, taking one calibration sample on each edge. Then place the Trax flat on the surface and take a calibration sample, then flip it over (roll it 180°) and take another sample. Next, starting with the Trax as shown on the right, take a calibration point with it being vertical (0°). Now tilt the Trax back 45° and take another calibration point (+45°), then tilt the device forward 45° and take another calibration point (-45°). Repeat this 3-point calibration process for the Trax with it resting on each of its 4 corners. Note that it is possible to perform an Accelerometer Calibration with as few as 12 sample points, although it generally is more difficult to obtain a good calibration with just 12 sample points. Also, the maximum number of calibration points is 18.

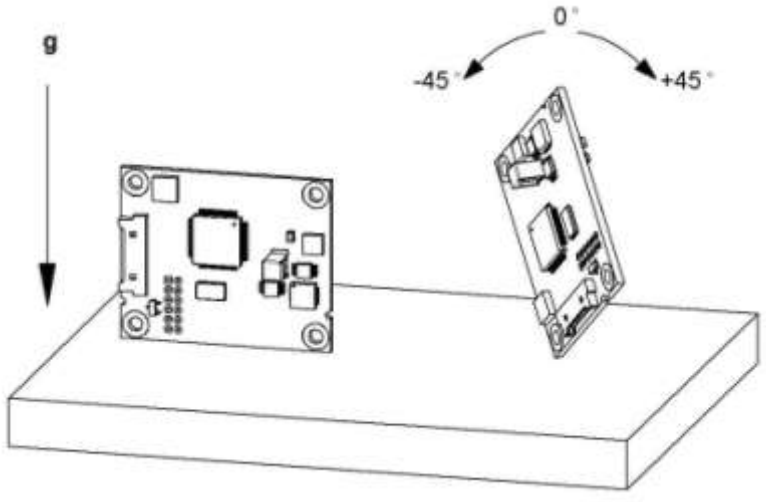


Figure 5-2: Accelerometer Calibration Starting Orientations

6 Getting Started with Trax Studio

The Trax Studio program puts an easy-to-use, graphical-user interface (GUI) onto the binary command language used by the Trax. Trax Studio is intended for evaluating, demonstrating, and calibrating the enclosed version of Trax ("Trax Enclosed"). Among other features, the program can log and save the outputs from the Trax to a file for off-line evaluation. Anything that can be done using Trax Studio also can be done using PNI's binary protocol, as discussed in Section 7.

6.1 Installation

Trax Studio is provided as an executable program which can be downloaded from PNI's website. It will work with Windows XP, Windows Vista, and Windows 7 operating systems. Check the PNI web page at www.pnicorp.com for the latest version.

Copy the "TraxStudio.msi" file onto your computer. Double-click on the icon and step through the Setup Wizard. The program will be installed into the following directory unless you direct it otherwise: Program Files\PNI Sensor Corporation\TRAX Studio\. A "Trax Studio" shortcut icon will be placed on your computer's desktop.

Now plug the Trax into the USB port of your computer. **Ensure the Trax is completely still when plugging it into the USB port, as the gyros initialize during the first five seconds after being plugged in.**

If you are using the Windows XP operating system, then the first time you plug in the Trax device it will launch the Found New Hardware Wizard. Select a "Yes…" button, then click on <Next> and proceed with the installation. The computer should find the required virtual communications port (VCP) driver by searching the internet, which may take a minute or two. If you are using Windows 7 the computer automatically searches for and installs the driver. If there is a problem with this, download the driver from FTDI's website at http://www.ftdichip.com/Drivers/VCP.htm.

You have now completed the installation of Trax Studio.

6.2 Trax Studio Header and Connecting to Trax Studio

If the Trax is not already plugged into the computer, then do so. Note that the module must be motionless when being plugged in and for 5 seconds afterwards, as this is when the gyros initialize.

Double-click on the Trax Studio icon to launch Trax Studio. Below is a picture of the Trax Studio header. The header includes "Module Information" and "Connection Settings", and

under the header are the various Trax Studio tabs, which are discussed in the subsequent sections. The header is the same regardless of which tab is selected.

To connect, set the "Serial" field to the appropriate COM port. To determine this, in Windows right click on "My Computer", select "Manage", then select "Device Manager". Expand "Ports" and note the port for "USB Serial Port". This should be the assigned COM port for the Trax.

Set the baud rate. The default is 38400, and this should be the setting the first time the Trax is used. Once a connection has been established, the desired baud rate can be changed on the Configuration Tab, as discussed in Section 6.4.1.

Click the <Connect> button. When the connection is established, the light to the left of "Status" will turn green, "Status" will change to "Connected @ [the baud rate]", the <Connect> button will now say <Disconnect>, the <Power Down> button will be live, and the "Device Information" section of the header will populate.

6.3 Trax Studio Footer and Saving/Applying Settings

Below is a picture of the Trax Studio footer. The footer includes 4 buttons which are discussed below. The footer is the same regardless of which tab is selected. Note that if a field is changed on any of the Trax Studio tabs, then either <Apply> or <Save> must be selected for the change to take effect.

Save

Clicking the <Save> button will save any changes made in Trax Studio to the Trax's onboard non-volatile and volatile memory.

Apply

Selecting the <Apply> button will apply any changes to the Trax's volatile memory, but not to the non-volatile memory. If the Trax is powered off/on, the settings will revert to whatever was last saved in the non-volatile memory.

Read

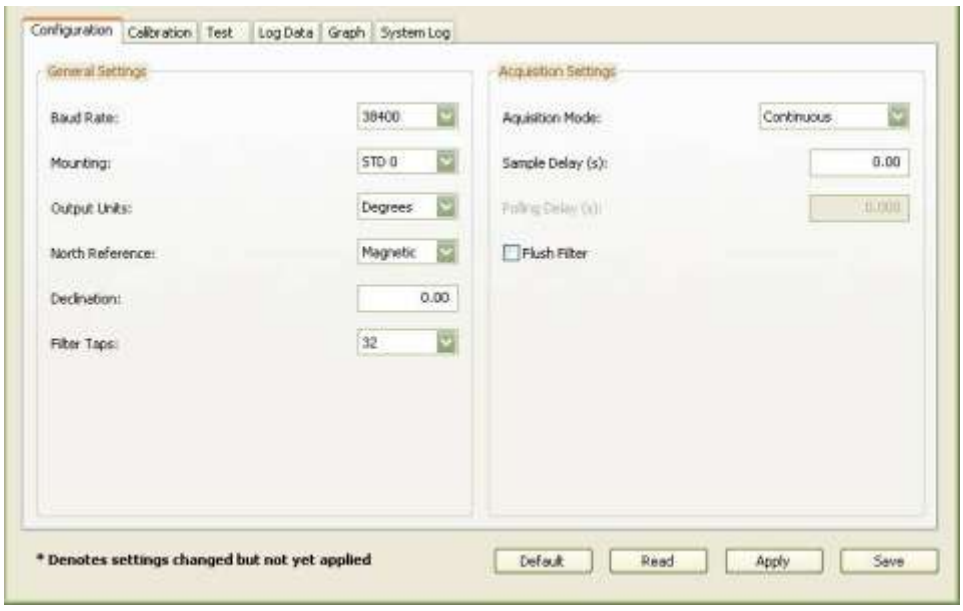
Clicking the <Read> button will read the current settings in the Trax's volatile memory and display them. This will change any item in bold, which indicates a setting was changed in Trax Studio but not applied to the Trax's volatile memory, back to regular type and the setting change will not be applied to the Trax's memory.

Default

Selecting the <Default> button will display the default settings, which are stored in Trax Studio. Selecting this button will not automatically apply these values, and either <Apply> or <Save> must be selected for the read values to be applied.

6.4 Configuration Tab

The Configuration Tab is shown below and its contents discussed in the following subsections. For any changes to take effect, the <Save> button must be selected. Clicking on the <Default> button will load the factory default values, although these must be saved to take effect. Clicking the <Retrieve> button will show the current settings of the device.



6.4.1 General Settings

Baud Rate

The baud rate can be altered by selecting the desired baud rate from the pull down menu, clicking on "Save", and then powering the device off and back on. The new baud rate will not take effect until the device has been powered off/on. The default baud rate is 38400.

Mounting

Trax Studio supports 16 mounting orientations, as previously illustrated in Figure 4-2. The default is "Standard".

Output Units

The Trax can output heading, pitch, and roll in either degrees or mils. The default is "Degrees". (There are 6400 mils in a circle, such that 1 degree = 17.7778 mils and 1 mil = 0.05625 degree.)

North Reference

When "Magnetic" is selected, the heading output will be relative to magnetic north. When "True" is selected, heading will be relative to true north, and the declination value should be entered in the next field. The default is "Magnetic".

Declination

The declination represents the heading difference between magnetic north and true north, and needs to be entered if "True" is selected as the "North Reference". Declination varies primarily with location, although it also gradually changes over time (years) for a given location. To find the declination for where the Trax will be used, go to http://www.ngdc.noaa.gov/geomagmodels/Declination.jsp.

Filter Taps

When operating the Trax in Compass Mode, the Trax will use a finite impulse response (FIR) filter to effectively provide a stable heading reading. When operating in AHRS Mode a completely different filtering method is used and the number of FIR Taps is not relevant.

The number of taps (or samples) represents the amount of filtering to be performed. Either 0, 4, 8, 16, or 32 taps may be selected, with zero taps representing no filtering. Note that selecting a larger number of taps can significantly slow the time for the initial sample reading and, if "Flush Filters" is selected, the rate at which data is output. The default setting is 32.

The FIR filtering operates on a first-in, first-out (FIFO) basis. For example, with FIR Taps set to 32, once the initial 32 samples are taken the next sample (#33) is included in the filtering and the initial sample (#1) is dropped from the filtering.

Flush Filter

The Flush Filter setting is only relevant when in Compass Mode, as it affects how the FIR filters are implemented. Flushing the FIR filter clears all the filter values so it is necessary to fully repopulate the filter before a good reading can be given. For example, if 32 FIR taps is set, then 32 new samples must be taken to provide a good reading. It is particularly prudent to flush the filter if the Sampling Delay is set to a non-zero value as this will purge old data. Note that flushing the filters increases the delay until data is output, with the length of the delay being directly correlated to the number of FIR taps. The default is not to Flush Filters.

6.4.2 Acquisition Settings

Acquisition Mode

When operating in Continuous Acquisition Mode, the Trax continuously outputs data to the host system. The rate is set by the Sample Delay. When operating in Polled Mode, Trax Studio simulates a host system and polls the Trax for a single measurement; but Trax Studio makes this request at a fixed rate which is set by the Polling Delay. In both cases data is continuously output, but in Continuous Acquisition Mode the Trax controls the data rate while in Polled Mode the Trax Studio program controls the data rate. Polled Mode is the default.

Sample Delay

The Sample Delay is relevant when Continuous Mode is selected. It is the time delay, in seconds, between completion of Trax sending one set of data and the start of sending the next sample set. If the delay is set to 0, then Trax will begin sending new data as soon as the previous data set has been sent. Note that the inverse of the Sample Delay is greater than the sample rate, since the Sample Delay does not include the actual measurement acquisition time. The default is 0.

Polling Delay

The Polling Delay is relevant when Polled Mode is selected. It represents the time delay, in seconds, between the completion of Trax Studio receiving one set of sampled data and requesting the next sample set. If the delay is set to 0, then Trax Studio requests new data as soon as the previous request is fulfilled. Note that the inverse of the Polling Delay is greater than the sample rate, since the Polling Delay does not include the actual measurement acquisition time. The default is 0.

6.5 Calibration and the Calibration Tab

As discussed in Section 5, a user calibration should be performed to optimize Trax performance. The Calibration Tab is shown below, and following this are discussions of how to set the calibration settings, how to perform a calibration, and how to interpret the results.

6.5.1 Calibration Settings

Calibration Type

The "Calibration Type" pull down menu establishes the type of calibration to be performed. The options are Full, 2D, Hard Iron Only, Limited Tilt Range, and Accelerometer. These are briefly discussed below and in more detail in Section 5.

Full Range – recommended calibration method when ≥45° of tilt is possible.

2D – recommended when the available tilt range is limited to ≤5°.

Hard Iron Only – serves as a hard iron recalibration to a prior calibration. If the hard iron distortion around the device changes, this procedure can bring the device back into specification more quickly than other methods.

Limited Tilt Range – recommended calibration method when >5° of tilt calibration is available, but tilt is restricted to <45°. (i.e. full range calibration is not possible.)

Accelerometer – The user should select this when accelerometer calibration will be performed. Accelerometer calibration is recommended every 6 to 12 months to

compensate for bias drift in the accelerometer. The Trax can also be returned to PNI for accelerometer calibration.

Number of Points

This establishes how many samples will be taken during the calibration. The minimum and recommended number of samples depends on the calibration method, and is summarized in Table 5-1. The maximum number of samples is 18.

Mag Coefficient Set & Accel Coefficient Set

At any one time, the Trax will use one set of magnetic calibration coefficients and one set of accelerometer calibration coefficients. The magnetic coefficients compensate for measured magnetic distortions in the host system as determined during a magnetic calibration. The accelerometer coefficients compensate for bias and offset of the accelerometers, as determined during an accelerometer calibration.

However, the Trax can store eight (8) sets of magnetic calibration coefficients and eight (8) sets of accelerometer calibration coefficients. This feature is useful if the compass will be placed in multiple locations that have different local magnetic field properties. The default is index number 0 and initially this is populated at PNI with factory-generated coefficients for the device itself. The other sets initially are unpopulated.

To store a coefficient set, first select the index number (0 to 7), then perform a calibration. The coefficient values will be stored in the defined index number, assuming the <Save> is selected after the calibration. To recall and use a different set of coefficients, change the "Mag Coefficient Set" and/or "Accel Coefficient Set" number, then click the <Save> button.

Automatic Sampling

If selected, the Trax will take a sample point once predefined minimum change and stability requirements have been satisfied. If the user wants to have more control over when the point will be taken then Auto Sampling should be deselected.

H/P/R Output During Cal

When selected, the heading, pitch, and roll of the device will be output below the sample number during a calibration. Using this feature, the user can monitor the device's orientation to easily follow the appropriate recommended calibration pattern. Since a calibration is being performed, these values are relative and should not be considered accurate.

Audible Feedback

If selected, Trax Studio will give an audible signal when a calibration sample is taken.

6.5.2 Performing a Calibration

Before proceeding, ensure you are familiar with the recommended calibration pattern corresponding to the "Type" selected. These are discussed in Section 5.

To perform a calibration, follow the following steps:

- Click the <Start> button to begin the calibration process.
- If "Automatic Sampling" is not checked the first sample will be taken automatically assuming the Trax is relatively stationary. After this, it is necessary to click the <Take Sample> button to take a calibration sample point. This should be repeated until the total number of samples is taken, changing the orientation of the device between samples as discussed in Section 5.1.
- If "Automatic Sampling" is checked the Trax needs to be held steady for a short time and then a sample automatically will be taken. Once the window indicates the next number, the device's orientation should be changed and held steady for the next sample. Once the pre-set number of samples has been taken (as set on the Configuration tab) the calibration is complete.

Regardless of whether "Automatic Sampling" is selected, two criteria must be met for a calibration sample to be taken. First, the Trax must be held steady enough to meet PNI-defined stability criteria. Second, the Trax's orientation must have changed enough to meet PNI-defined orientation change criteria.

If "H/P/R Output During Cal" is selected, then the "Heading", "Pitch", and "Roll" fields will be populated in real-time once the <Start> button is selected. Note that the readings in these fields are relative, since calibration is in process.

6.5.3 Calibration Results

Once the calibration is complete the "Calibration Results" section will indicate the quality of the calibration. This may take a few seconds to populate. The primary score of concern is the MagCalScore or AccelCalScore, depending on whether a magnetic or accelerometer calibration was performed. The other parameters provide information that may assist in improving the MagCalScore should it be unacceptably high. If a calibration is acceptable, then click the <Save> button to save the calibration coefficients to the coefficient set defined on the Configuration Tab.

Note: If a calibration is aborted, all the score's will read "179.80", and the calibration coefficients will not be changed. (Clicking the <Save> button will not change the calibration coefficients.)

Mag Cal

Represents the over-riding indicator of the quality of a magnetic calibration. Acceptable scores are <1 for Full Range Calibration and <2 for other methods. Note that it is possible to obtain acceptable Distribution Error and Tilt Error scores and still have a rather high Mag Cal value. The most likely reason for this is the Trax is close to a source of magnetic distortion that is not fixed with respect to the device.

Accel Cal

Represents the quality of an Accelerometer Calibration. The score should be <1.

Distribution Error

Indicates if the distribution of sample points is good, with an emphasis on the heading distribution. The score should be 0. Significant clumping or a lack of sample points in a particular section can result in a poor score. Distribution is not calculated for an Accelerometer Calibration.

Tilt Error

Indicates if the Trax experienced sufficient tilt during the calibration, taking into account the calibration method. The score should be 0. Tilt Error is not calculated for an Accelerometer Calibration.

Tilt Range

This reports the larger of either half the full pitch range or half the full roll range of all sample points. For example, if the Trax is pitched +10° to -20º, and rolled +25º to -15º, the Tilt Range value would be 20º, as derived from [+25º - {-15º}]/2. For Full Range Calibration and Hard Iron Only Calibration, this should be ≥45°. For 2D Calibration, this ideally would be ~2°. For Limited Tilt Range Calibration the value should be as large as possible given the user's constraints. Tilt Range is not calculated for an Accelerometer Calibration.

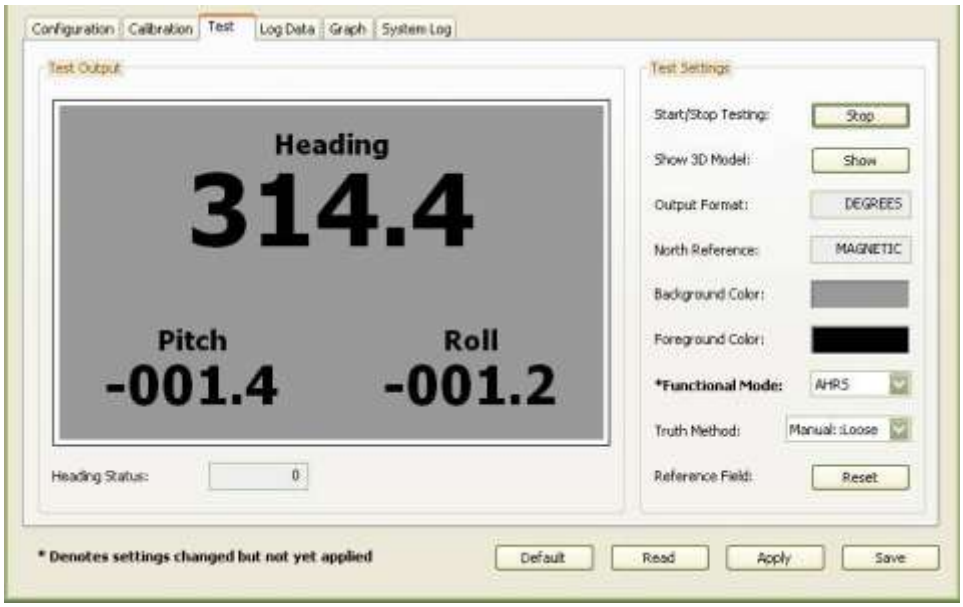
Mag Factory Reset & Accel Factory Reset

Clicking the Mag Factory Reset and/or Accel Factory Reset will reset the calibration coefficients to those established at PNI. Note that the mag factory coefficients will not take into account magnetic influences inherent in the host system, which could result in very large heading errors. And the accel factory coefficients will not correct for accelerometer drift, which may become significant over an extended period (6 – 12 months, typically). If either of these Reset buttons are selected, it is necessary to click <Save> or <Apply> to have the factory coefficients take effect.

6.6 Test Tab

The Test Tab is used to demonstrate and evaluate the performance of the Trax. The Heading, Pitch, and Roll are output during testing, as well as the Heading Status.

The **Heading Status** provides an indication of the accuracy of the heading. A green box represents a heading accuracy of <2°, a yellow box means the heading uncertainty is approximately 2° to 10°, and a red box means the uncertainty is >10°. These heading uncertainties assume the Trax was properly calibrated in a clean magnetic environment.



Start/Stop Testing

Clicking the <Start> button results in the Heading, Pitch, and Roll values being updated on the Test Tab screen, as well as the Heading Status.

If the Acquisition Mode is set to "Continuous", then the data will be continuously updated. The button will change to read <Stop>, such that clicking it again will stop the screen from updating.

If the Acquisition Mode is set to "Single", then only one measurement will be displayed on the screen. The button will briefly gray out while the data is being output to the screen, then return to reading <Start>.

Show 3D Model

Selecting the <Show> button launches the 3D Model window, as shown below.

Clicking the <Start> button begins continuous updating of the orientation of the rendered model, and of the heading, pitch, and roll output fields. The <Start> button on the Test Tab screen and on the 3D Model screen are linked such that selecting either of them will stop or start both screens.

Clicking on <Fullscreen> will expand the window to the full computer screen, and the button will now read <Windowed>. Clicking <Windowed> will shrink the window back down.

Output Format & North Reference

The "Output Format" and "North Reference" fields mimic the settings on the Configuration Tab. To change these, return to the Configuration Tab, make the change, then <Apply> or <Save> the change.

Background & Foreground Color

The foreground and background colors of the screen can be changed by the user. Simply click on the color square and select the new desired color. The change in color automatically is saved. The default is black lettering on a grey background.

Functional Mode

The Trax can operate either in AHRS Mode or Compass Mode. While the Trax is intended to be used as an AHRS, there are times when it is necessary or beneficial to

place it in Compass Mode. Specifically, it is necessary to calibrate the Trax in Compass Mode. (This is handled automatically in Trax Studio, so it is not necessary for the user to place the Trax in Compass Mode when doing a calibration in Trax Studio.) Also, it may be beneficial to operate in Compass Mode to conserve battery life, since in Compass Mode the Trax turns off the gyros, generally uses less CPU power, and can be placed in Sleep Mode to significantly reduce current consumption.

Truth Method

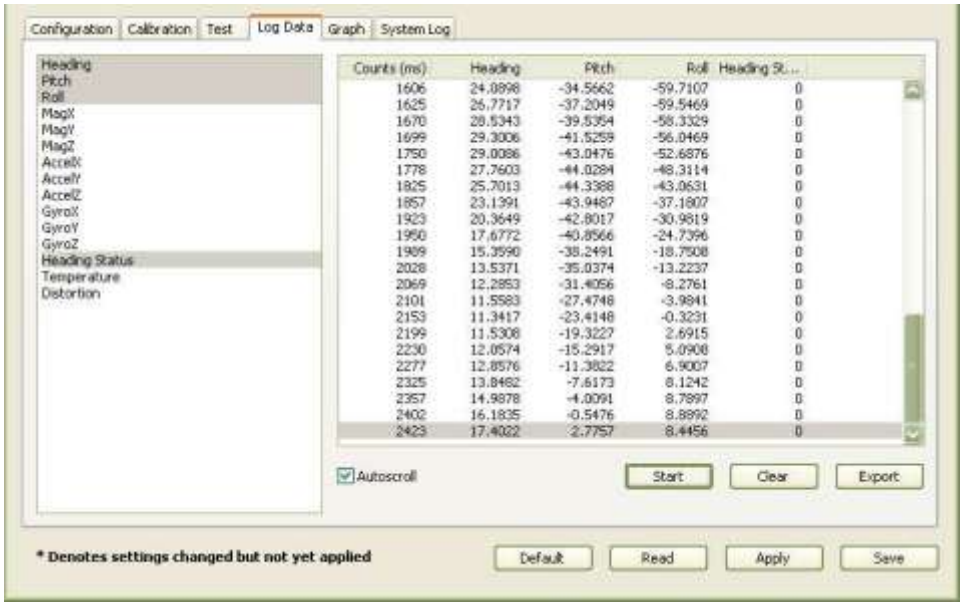
This field allows the user to have control over the breadth of criteria used to establish if the local magnetic field conforms to the reference magnetic field criteria. "Auto" is the default.

Reference Field Reset

Clicking the Reference Field <Reset> button re-establishes the criteria for a clean magnetic field. After clicking this button the Heading Status box will go green. Assuming an accurate heading reading is desired, this should be done only when the user is confident the local magnetic field is free from distortions. For the purpose of demonstrating the general capabilities of the Trax a distortion-free local magnetic field may not be required, but the user should realize the heading reading likely will not meet the accuracy specification.

6.7 Log Data Tab

Trax Studio can capture measurement data and then export it to a text file.



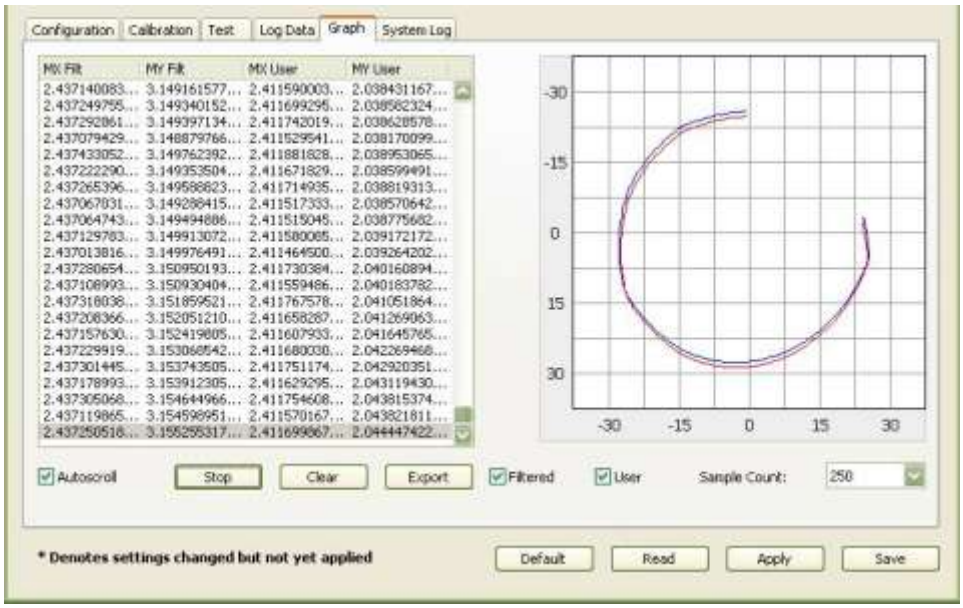
To acquire data and export it, follow the procedure below:

- Select the parameters you wish to log in the window on the left. Use Shift -Click and Ctrl-Click to select multiple items. In the screen shot above, “Heading”, “Pitch”, “Roll”, and “Heading Status” were selected. Note that Heading Status can be 0, 1, or 2, corresponding to “green”, “yellow”, or “red”.
- Click the <Start> button to start logging. The <Start> button changes to a <Stop> button after data logging begins.
- Click the <Stop> button to stop logging data.
- Click the <Export> button to save the data to a file.
- Click the <Clear> button to clear the data from the window.

Note that the “Distortion” log indicates if the magnetic field is >|±125 µT| for any of the magnetic sensors. It is only applicable in Compass Mode, and will always read “FALSE” in AHRS Mode.

6.8 Graph Tab

The Graph Tab provides a plot of the measured field strength on the x-axis and y-axis magnetic sensors.



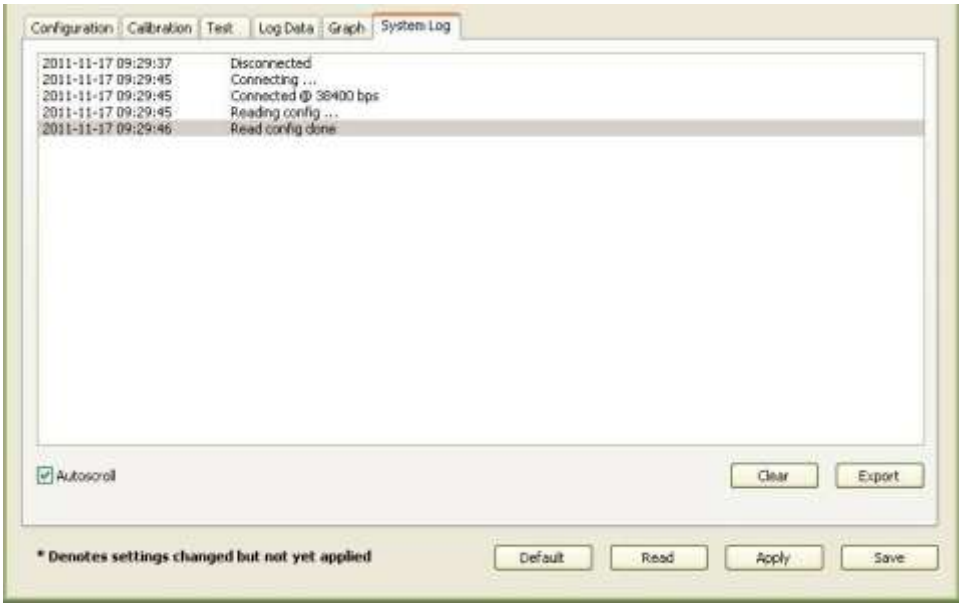
The “Filt” data and plot (blue) provides magnetic field strength measurements after the FIR filter taps are applied, but prior to applying the user calibration coefficients. The “User” data and plot (red) provides data after applying the user calibration coefficients. In AHRS Mode the data and plots are identical, while in Compass Mode there is an offset which represents

the effect of the calibration coefficients. The Graph Tab normally would be used in Compass Mode because of this. The graph can be used to visually see hard and soft iron effects within the environment measured by the Trax, as well as corrected output after a user calibration has been performed.

The data can be saved to a .txt log file by clicking <Export>. To clear the data, select <Clear>. To clear both the data and the plot, select <Apply>.

6.9 System Log Tab

The System Log tab shows all communication between Trax Studio and Trax. Closing Trax Studio will erase the system log. Select the <Export> button, at the bottom right of the screen, to save the system log to a text file.



7 Operation with PNI Binary Protocol

The Trax utilizes PNI's binary protocol that is transmitted over either a USB virtual communication port or an RS232 UART. Communication parameters should be set as follows:

Table 7-1: Communication Port Configuration

Parameter	Value
Number of Data Bits	8
Start Bits	1
Stop Bits	1
Parity	none

7.1 Datagram Structure

The data structure is shown below:

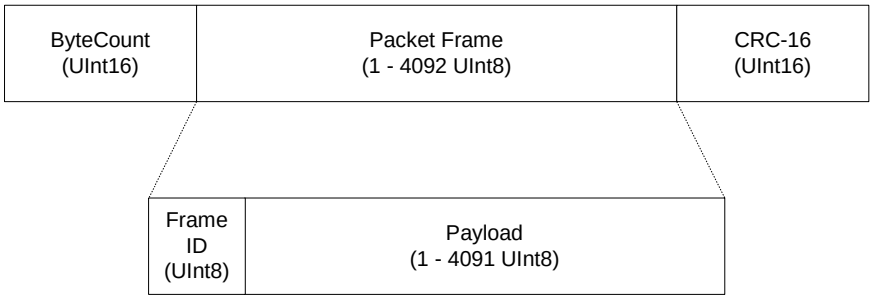


Figure 7-1: Datagram Structure

The ByteCount is the total number of bytes in the packet including the CRC-16 (checksum). The CRC-16 is calculated starting from the ByteCount to the last byte of the Packet Frame. The ByteCount and CRC-16 are always transmitted in big Endian. Two examples follow.

Example: The complete packet for the kGetModInfo command, which has no payload is:

00 05	01	EF D4
ByteCount	Frame ID	Checksum

Example: Below is a complete sample packet to start a 2D Calibration (kStartCal):

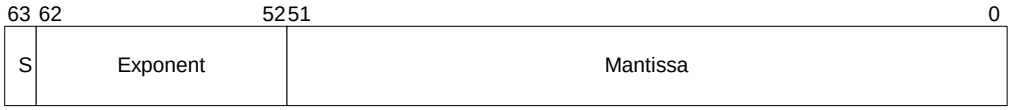
00 09	0A	00 00	00 14	5C F9
ByteCount	Frame ID	CalOption (MSBs)	CalOption (2D Calibration)	Checksum

7.2 Parameter Formats

Note: *Floating-point based parameters conform to ANSI/IEEE Std 754-1985. Please refer to the Standard for more information. PNI also recommends the user refer to the compiler's instructions to understand how the compiler implements floating-point format.*

64-Bit Floating Point (Float64)

Below is the 64-bit float format in big Endian. In little Endian, the bytes are in reverse order in 4 byte groups. (eg. big Endian: ABCD EFGH; little Endian: DCBA HGFE).

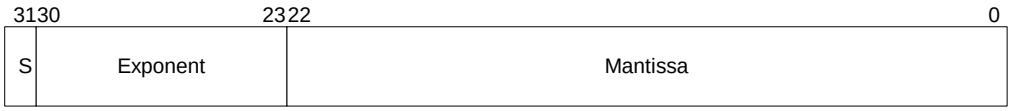


The value (v) is determined as:

v = (-1)S * 2(Exponent-1023) * 1.Mantissa, if and only if 0 < Exponent < 2047

32-Bit Floating Point (Float32)

Shown below is the 32-bit float format in big Endian. In little Endian format, the 4 bytes are in reverse order (LSB first).

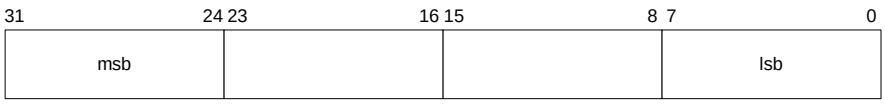


The value (v) is determined as:

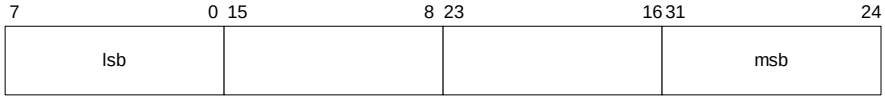
v = (-1)S * 2(Exponent-127) * 1.Mantissa, if and only if 0 < Exponent < 255

Signed 32-Bit Integer (SInt32)

SInt32-based parameters are signed 32-bit numbers (2's compliment). Bit 31 represents the sign of the value, where 0=positive and 1=negative.



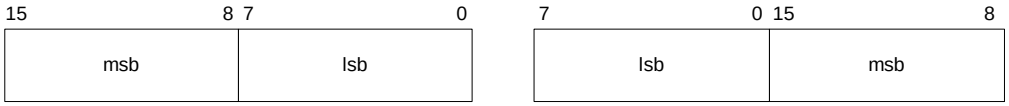
Big Endian



Little Endian

Signed 16-Bit Integer (SInt16)

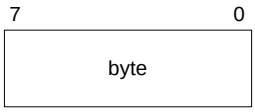
SInt16-based parameters are signed 16-bit numbers (2's compliment). Bit 15 represents the sign of the value, where 0=positive and 1=negative.



Big Endian Little Endian

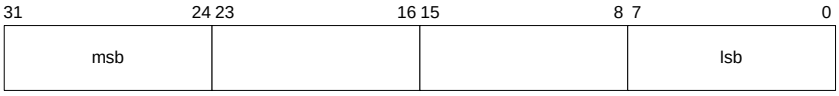
Signed 8-Bit Integer (SInt8)

UInt8-based parameters are unsigned 8-bit numbers. Bit 7 represents the sign of the value, where 0=positive and 1=negative.

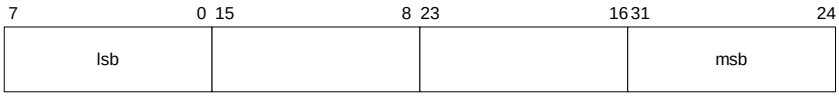


Unsigned 32-Bit Integer (UInt32)

UInt32-based parameters are unsigned 32-bit numbers.



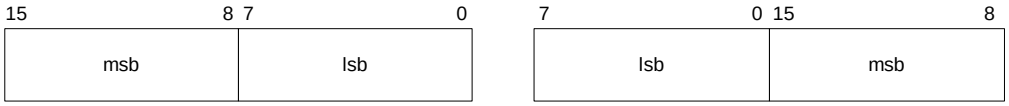
Big Endian



Little Endian

Unsigned 16-Bit Integer (UInt16)

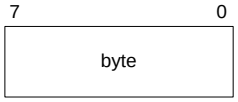
UInt16-based parameters are unsigned 16-bit numbers.



Big Endian Little Endian

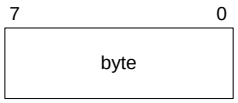
Unsigned 8-Bit Integer (UInt8)

UInt8-based parameters are unsigned 8-bit numbers.



Boolean

Boolean is a 1-byte parameter that MUST have the value 0=FALSE or 1=TRUE.



7.3 Commands Overview

Table 7-2 provides a summary of the basic commands available with the Trax. These commands are discussed in the following subsections.

Table 7-2: Trax Binary Command Set

Frame ID_d	Command	Description
Set Up		
1	kGetModInfo	Queries the device's type and firmware revision.
2	kGetModInfoResp	Response to kGetModInfo
6	kSetConfig	Sets internal configurations in Trax
19	kSetConfigDone	Response to kSetConfig
7	kGetConfig	Queries Trax for the current internal configuration
8	kGetConfigResp	Response to kGetConfig
119	kSetMagTruthMethod	Sets if dip angle & radius establish mag truth (standard) or additional criteria (tight).
120	kGetMagTruthMethod	Queries for standard or tight truth method.
121	kGetMagTruthMethodResp	Response to kGetMagTruthMethod
9	kSave	Saves the current internal configuration and any new user calibration coefficients to non-volatile memory.
16	kSaveDone	Response to kSave
Operation		
110	kSetResetRef	Establishes criteria for the reference magnetic field.
24	kSetAcqParams	Sets the sensor acquisition parameters
26	kSetAcqParamsDone	Response to kSetAcqParams
25	kGetAcqParams	Queries for the sensor acquisition parameters
27	kGetAcqParamsResp	Response to kGetAcqParams
3	kSetDataComponents	Sets the data components to be output.
4	kGetData	Queries the Trax for data
5	kGetDataResp	Response to kGetData
21	kStartContinuousMode	Commands the Trax to output data at a fixed interval
22	kStopContinuousMode	Stops data output when in Continuous Mode

Calibration		
10	kStartCal	Commands the Trax to start user calibration
11	kStopCal	Commands the Trax to stop user calibration
31	kTakeUserCalSample	Commands the Trax to take a sample during user calibration
17	kUserCalSampleCount	Sent from the Trax after taking a calibration sample point
18	kUserCalScore	Contains the calibration score
29	kSetFactoryMagCoeff	Resets magnetometer calibration coefficients to original factory-established values
30	kSetFactoryMagCoeffDone	Response to kSetFactoryMagCoeff
36	kSetFactoryIAccelCoeff	Resets accelerometer calibration coefficients to original factory-established values
37	kSetFactoryAccelCoeffDone	Respond to kSetFactoryAccelCoeff
Compass Mode		
79	kSetFunctionalMode	Puts Trax in Compass Mode or AHRS Mode
80	kGetFunctionalMode	Queries for Compass Mode or AHRS Mode
81	kGetFunctionalModeResp	Response to kGetFunctionalMode
12	kSetFIRFilters	Sets the FIR filter settings for the magnetometer & accelerometer sensors.
20	kSetFIRFiltersDone	Response to kSetFIRFilters
13	kGetFIRFilters	Queries for the FIR filter settings for the magnetometer & accelerometer sensors.
14	kGetFIRFiltersResp	Contains the FIR filter settings for the magnetometer & accelerometer sensors.
15	kPowerDown	Powers down the module
28	kPowerDownDone	Response to kPowerDown
23	kPowerUpDone	Confirms the Trax has received a signal to power up

7.4 Set-Up Commands

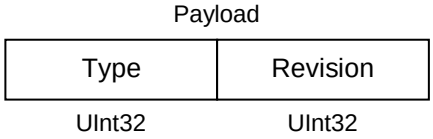
7.4.1 Module Information

kGetModInfo (frame ID 1_d)

This frame queries the device's type and firmware revision number. The frame has no payload.

kGetModInfoResp (frame ID 2_d)

The response to kGetModInfo is given below. The payload contains the device type identifier followed by the firmware revision number.

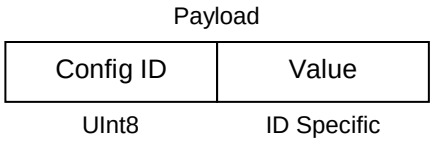


Note that the Type and Revision can be decoded from the binary format to character format using the ASCII standard. For example, the hex string “00 0D 02 54 52 41 58 31 32 30 38 C7 87” can be decoded to read “Trax 1208”.

7.4.2 Module Configuration

kSetConfig (frame ID 6_d)

This frame sets internal configurations in the Trax. The first byte of the payload is the configuration ID followed by a format-specific value. These configurations can only be set one at time. To save these in non-volatile memory, the kSave command must be issued.



Example: To configure the declination, the payload would look like:

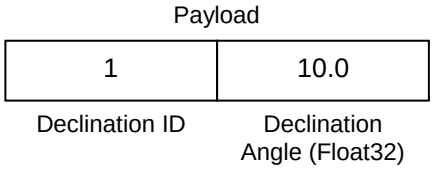


Table 7-3: Configuration Identifiers

Settings	Config. ID_d	Format	Values / Range	Default
kDeclination	1	Float32	-180˚ to +180˚	0
kTrueNorth	2	Boolean	True or False	False
kBigEndian	6	Boolean	True or False	True
kMountingRef	10	UInt8	1 = STD 0° 2 = X UP 0° 3 = Y UP 0° 4 = STD 90° 5 = STD 180° 6 = STD 270° 7 = Z DOWN 0° 8 = X UP 90° 9 = X UP 180° 10 = X UP 270° 11 = Y UP 90° 12 = Y UP 180° 13 = Y UP 270° 14 = Z DOWN 90° 15 = Z DOWN 180° 16 = Z DOWN 270°	1
kUserCalNumPoints	12	UInt32	4 – 18	12
kUserCalAutoSampling	13	Boolean	True or False	True
kBaudRate	14	UInt8	4 – 2400 5 – 3600 6 – 4800 7 – 7200 8 – 9600 9 – 14400 10 – 19200 11 – 28800 12 – 38400 13 – 57600 14 - 115200	12
kMilOut	15	Boolean	True or False	False
kHPRDuringCal	16	Boolean	True or False	True
kMagCoeffCopySet	18	UInt32	0 - 7	0
kAccelCoeffCopySet	19	UInt32	0 - 7	0

Configuration parameters and settings for kSetConfig:

kDeclination (Config. ID 1d)

This sets the declination angle to determine True North heading. Positive declination is easterly declination and negative is westerly declination. This is not applied unless kTrueNorth is set to TRUE.

kTrueNorth (Config. ID 2_d)

Flag to set compass heading output to true north heading by adding the declination angle to the magnetic north heading.

kBigEndian (Config. ID 6_d)

Sets the Endianness of packets. TRUE is Big Endian. FALSE is Little Endian.

kMountingRef (Config. ID 10_d)

This sets the reference orientation for the Trax. Please refer to Figure 4-2 for additional information.

kUserCalNumPoints (Config. ID 12_d)

The user must select the number of points to take during a calibration. The number of sample points must be within the listed "Allowable Range" or the Trax may not work properly. Calibration generally is not as good if less than the "Minimum Recommended" is selected, but may be acceptable.

Table 7-4: Sample Points

Calibration Mode	Number of Samples	
	Allowable Range	Recommended Pattern
Full Range Calibration	10 to 18	12
Limited Tilt Calibration	10 to 18	12
2D Calibration	10 to 18	12
Hard Iron Only	4 to 18	6
Accelerometer	18	18

kUserCalAutoSampling (Config. ID 13_d)

This flag is used during user calibration. If set to TRUE, the Trax automatically takes calibration sample points once the minimum change and stability requirements are met. If set to FALSE, the device waits for kTakeUserCalSample to take a sample with the condition that a magnetic field vector component delta is greater than 5 µT from the last sample point. If the user wants to have maximum control over when the calibration sample point are taken then this flag should be set to FALSE.

kBaudRate (Config. ID 14_d)

Baud rate index value. A power-down, power-up cycle is required when changing the baud rate.

kMilOut (Config. ID 15_d)

Sets the output units as mils (TRUE) or degrees (FALSE). The default is FALSE.

kHPRDuringCal (Config. ID 16_d)

This flag sets whether or not heading, pitch, and roll data are output simultaneously while the Trax is being calibrated. The default is TRUE, such that heading, pitch, and roll are output during calibration. FALSE disables simultaneous output.

kMagCoeffCopySet (Config. ID 18_d)

This command provides the flexibility to store up to eight (8) sets of magnetometer calibration coefficients in the Trax. The default is set number 0. To store a set of coefficients, first establish the set number (number 0 to 7) using kMagCoeffCopySet, then perform the magnetometer calibration. The coefficient values will be stored in the defined set number. This feature is useful if the compass will be placed in multiple locations that have different local magnetic field properties.

kAccelCoeffCopySet (Config. ID 19_d)

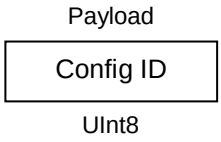
This command provides the flexibility to store up to eight (8) sets of accelerometer calibration coefficients in the Trax. The default is set number 0. To store a set of coefficients, first establish the set number (number 0 to 7) using kAccelCoeffCopySet, then perform the accelerometer calibration. The coefficient values will be stored in the defined set number.

kSetConfigDone (frame ID 19_d)

This frame is the response to kSetConfig frame. The frame has no payload.

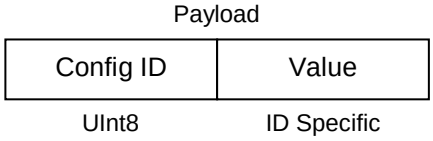
kGetConfig (frame ID 7_d)

This frame queries the Trax for the current internal configuration value. The payload contains the configuration ID requested.

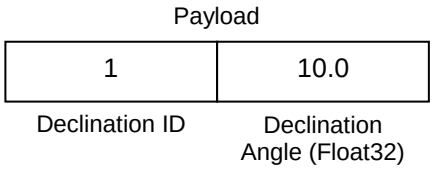


kGetConfigResp (frame ID 8_d)

The response to kGetConfig is given below. The payload contains the configuration ID and value.

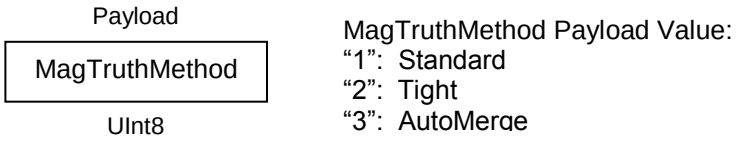


Example: If a request to get the set declination angle, the payload would look like:



kSetMagTruthMethod (frame ID 119 $_d$)

This frame allows the user to have control over the breadth of criteria used to establish if the local magnetic field conforms to the reference magnetic field criteria. The "AutoMerge" criteria is the default. The payload is defined below.



kGetMagTruthMethod (frame ID 120 $_d$)

This frame queries the setting of the Mag Truth Method. It has no payload.

kGetMagTruthMethodResp (frame ID 121 $_d$)

This frame is the response of kGetMagTruthMethod and the payload is the same as for kSetMagTruthMethod.

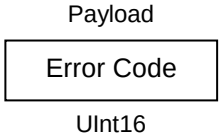
7.4.3 Saving Settings

kSave (frame ID 9$_d$)

This frame commands the Trax to save internal configurations and user calibration to non-volatile memory. Internal configurations and user calibration are restored on power up. The frame has no payload. This is the ONLY command that causes the device to save information to non-volatile memory.

kSaveDone (frame ID 16 $_d$)

This frame is the response to kSave frame. The payload contains a UInt16 error code: 0 indicates no error; 1 indicates an error when attempting to save data to memory.



7.5 Measurement Commands

7.5.1 Setting the Reference Magnetic Field Criteria

Prior to operating the Trax in AHRS mode it is necessary to establish the criteria for a known distortion-free local field. This should be done with the Trax installed in the host system, as the distortion presented by the host system is constant and will be compensated for by the Trax algorithms.

kSetResetRef (frame ID 110 $_d$)

This frame re-aligns the Trax 9-axis heading to the 6-axis (mag and accel) heading and establishes the criteria for the reference magnetic field. The frame should be sent when the user is confident the local magnetic field is not distorted. It has no payload.

7.5.2 Data Acquisition Parameters

kSetAcqParams (frame ID 24 $_d$)

This frame sets the sensor acquisition parameters in the Trax. The payload should contain the following:

Payload

AcquisitionMode	FlushFilter	PNIReserved	SampleDelay
UInt8	UInt8	Float32	Float32

AcquisitionMode:

This flag sets whether output will be presented in Continuous or Polled Acquisition Mode. Continuous Mode is TRUE and is the default. Polled Mode should be selected when the host system will poll the Trax for each data set. Continuous Mode should be selected if the user will have the Trax output data to the host system at a relatively fixed rate.

FlushFilter:

This is only relevant in Compass Mode. Setting this flag to TRUE results in the FIR filter being flushed (cleared) after every measurement. The default is FALSE.

Flushing the filter clears all tap values, thus purging old data. This can be useful if a significant change in heading has occurred since the last reading, as the old heading data would be in the filter. Once the taps are cleared, it is necessary to fully repopulate the filter before data is output. For example, if 32 FIR taps is set,

32 new samples must be taken before a reading will be output. The length of the delay before outputting data is directly correlated to the number of FIR taps.

PNIReserved:

These 4 bytes serve no function. PNI recommends populating the bytes with 0.

SampleDelay:

The SampleDelay is relevant when the Continuous Acquisition Mode is selected. It is the time delay, in seconds, between completion of Trax sending one set of data and the start of sending the next data set. The default is 0 seconds, which means Trax will send new data as soon as the previous data set has been sent. Note that the inverse of the SampleDelay is somewhat greater than the actual sample rate, since the SampleDelay does not include actual acquisition time.

kSetAcqParamsDone (frame ID 26 $_d$)

This frame is the response to kSetAcqParams frame. The frame has no payload.

kGetAcqParams (frame ID 25 $_d$)

This frame queries the unit for acquisition parameters. The frame has no payload.

kGetAcqParamsResp (frame ID 27 $_d$)

This frame is the response to kGetAcqParams frame. The payload should contain the same payload as the kSetAcqParams frame.

7.5.3 Data Components

kSetDataComponents (frame ID 3$_d$)

This frame defines what data is output when kGetData is sent. Table 7-5 summarizes the various data components and more detail follows this table. Note that this is not a query for the device's model type and software revision (see kGetModInfo). The first byte of the payload indicates the number of data components followed by the data component IDs. Note that the sequence of the data components defined by kSetDataComponents will match the output sequence of kGetDataResp.

Payload

ID Count	ID 1	ID 2	ID 3	…….
UInt8	UInt8	UInt8	UInt8	

Example: To query for heading and heading status, the payload should contain:

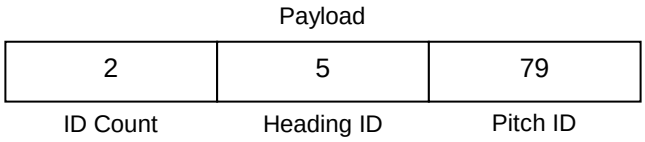


Table 7-5: Component Identifiers

Component	Component ID_d	Format	Units
kHeading	5	Float32	degrees
kPitch	24	Float32	degrees
kRoll	25	Float32	degrees
kHeadingStatus	79	UInt8	value
kQuaternion	77	4x Float32	quaternion
kTemperature	7	Float32	˚ Celsius
kDistortion	8	Boolean	True or False (Default)
kCalStatus	9	Boolean	True or False (Default)
kAccelX	21	Float32	G
kAccelY	22	Float32	G
kAccelZ	23	Float32	G
kMagX	27	Float32	μT
kMagY	28	Float32	μT
kMagZ	29	Float32	μT
kGyroX	74	Float32	radians/sec
kGyroY	75	Float32	radians/sec
kGyroZ	76	Float32	radians/sec

Component types are listed below. All are read-only values.

kHeading, kPitch, kRoll (Component IDs 5_d, 24_d, 25_d)

Provides compass heading, pitch and roll outputs. The heading range is 0.0˚ to +359.9˚, the pitch range is -90.0˚ to +90.0˚, and the roll range is to -180.0˚ to +180.0˚.

kHeadingStatus (Component IDs 79_d)

The heading status provides an indication of the uncertainty of the heading. "1" represents a heading uncertainty of <2°, "2" means the heading uncertainty is approximately 2° to 10°, and "3" means the uncertainty is >10°.

Quaternion (Component ID 77_d)

The quaternion values generated by the Trax algorithm are output in one data package that contains the four quaternions. The quaternions are output as Q0, Q1,

Q2, and Q3, where Q3 is the scalar quaternion. When in AHRS Mode, heading, pitch, and roll are subsequently calculated from these quaternions.

kTemperature (Component ID 7_d)

This value is provided by the device's internal temperature sensor. Its value is in degrees Celsius and has an accuracy of ±3° C.

kDistortion (Component ID 8_d)

This flag indicates at least one magnetometer axis reading is beyond ±125 µT. It is only applicable in Compass Mode, and will always read "FALSE" in AHRS Mode.

kCalStatus (Component ID 9_d)

This flag indicates the user calibration status. False means it is not user calibrated and this is the default value.

kAccelX, kAccelY & kAccelZ (Component IDs 21_d, 22_d, 23_d)

These values represent the accelerometer sensor data for the x, y, and z axis, respectively. The values are normalized to g (Earth's gravitational force).

kMagX, kMagY & kMagZ (Component IDs 27_d, 28_d, 29_d)

These values represent the magnetic sensor data for the x, y, and z axis, respectively. The values are given in µT.

kGyroX, kGyroY, kGyroZ (Component IDs 74_d, 75_d, 76_d)

These values represent the gyroscope sensor data for rotation around the x, y, and z axis, respectively. The values are in radians per second.

7.5.4 Making a Measurement

kGetData (frame ID 4_d)

If the Trax is configured to operate in Polled Acquisition Mode (see kSetAcqParams), then this frame requests a single measurement data set. The frame has no payload.

kStartContinuousMode (frame ID 21_d)

If the Trax is configured to operate in Continuous Acquisition Mode (see kSetAcqParams), then this frame initiates the outputting of data at a relatively fixed data rate, where the data rate is established by the SampleDelay parameter. The frame has no payload.

kStopContinuousMode (frame ID 22_d)

This frame commands the Trax to stop data output when in Continuous Acquisition Mode. The frame has no payload.

kGetDataResp (frame ID 5_d)

The response to kGetData and kStartContinuousMode is kGetDataResp. The specific data fields that will be output (ID 1, Value ID 1, etc.) should have been previously established by the kSetDataComponents command frame.

Payload

ID Count	ID 1	Value ID 1	ID 2	Value ID 2	ID 3	Value ID 3
UInt8	UInt8	ID Specific	UInt8	ID Specific	UInt8	ID Specific

Example: If heading and heading status are set to be output per the kSetDataComponents command, the payload would look like:

Payload

2	5	359.9	79	1
ID Count	Heading ID	Heading (Float32)	Heading Status ID	Heading Status (UInt8)

7.6 Calibration Commands

7.6.1 User Calibration Commands

First, note that in order to perform a user calibration, it is necessary to place the Trax in Compass Mode, as discussed in Section 7.7. Note that Trax allows for a maximum of 12 calibration points.

kStartCal (frame ID 10_d)

This frame commands the Trax to start user calibration with the current sensor acquisition parameters, internal configurations and FIR filter settings.

Payload

CalOption
UInt32

CalOption Payload Value:
"10_d" or "$0A_h$": Full Range Calibration (default)
"20_d" or "14_h": 2D Calibration
"30_d" or "$1E_h$": Hard Iron Only Calibration
"40_d" or "28_h": Limited Tilt Range Calibration
"100_d" or "64_h": Accelerometer Calibration

Note: The payload needs to be 32 bit (4 byte). If no payload is entered or if less than 4 bytes are entered, the unit will default to the previous calibration method.

The CalOption values are given below, along with basic descriptions of the options.

Full Range Calibration

Recommended calibration method when >45° of tilt is possible. Can be used for between 20° and 45° of tilt, but accuracy will not be as good

2D Calibration

Recommended when the available tilt range is limited to ≤5°. Can be used for 5° to 10° of tilt, but accuracy will not be as good.

Hard Iron Only Calibration

Recalibrates the hard iron offset for a prior calibration. If the local field hard iron distortion has changed, this calibration can bring the Trax back into specification.

Limited Tilt Range Calibration

Recommended calibration method when >5° of tilt calibration is available, but tilt is restricted to <45°. (i.e. full range calibration is not possible.)

Accelerometer Calibration

Select this when an accelerometer calibration will be performed.

Below is a complete sample packet to start a 2D Calibration (kStartCal):

00 09	0A	00 00	00 14	5C F9
ByteCount	Frame ID	CalOption (MSBs)	CalOption (2D Calibration)	Checksum

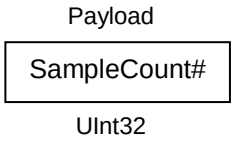
Heading, pitch and roll information is output via the kGetDataResp frame during the calibration process. This feature provides guidance during the calibration regarding calibration sample point coverage. During calibration, in the kGetDataResp frame, the number of data components is set to be 3 and then followed by the data component ID-value pairs. The sequence of the component IDs are kHeading, kPitch and kRoll.

kTakeUserCalSample (frame ID 31_d)

This frame commands the Trax to take a sample during user calibration. The frame has no payload.

kUserCalSampleCount (frame ID 17 $_d$)

This frame is sent from the Trax after taking a calibration sample point. The payload contains the sample count with the range of 1 to 18.



kStopCal (frame ID 11$_d$)

This command aborts the calibration process. The prior calibration results are retained.

7.6.2 Performing a User calibration

The steps below provide an example of the steps to perform a user calibration.

- Using the kSetParam command, set the number of tap filters to 0.
- Using the kSetConfig command, set kUserCalAutoSampling. "False" is generally recommended, but "True" may be more convenient.
- Using the kSetConfig command, set kCoeffCopySet (magnetometer calibration) and/or kAccelCoeffCopySet (accelerometer calibration). These fields allow the user to save multiple sets of calibration coefficients. "0" is the default.
- Using the kSetConfig command again, set kUserCalNumPoints to the appropriate number of calibration points.
- Initiate a calibration using the kStartCal command. Note that this command requires indentifying the type of calibration procedure (i.e. Full Range, 2D, etc.).
- Follow the appropriate calibration procedure, as discussed in Section 5. If kUserCalAutoSampling was set to "False", then send a kTakeUserCalSample command when ready to take a calibration point. If kUserCalAutoSampling was set to "True", then look for kUserCalSampCount to confirm when a calibration point has been taken. During the calibration process, heading, pitch, and roll information will be output from the Trax, and this can be monitored using kDataResp.
- When the final calibration point is taken, the device will present the calibration score using kUserCalScore.
- If the calibration is acceptable (see Section 7.6.2), save the calibration coefficients using kSave.

7.6.3 Calibration Score

kUserCalScore (frame ID 18 $_d$)

The calibration score is automatically sent upon taking the final calibration point. The payload is defined below, and the various payload components are discussed after this.

Payload

MagCalScore	Bytes 5-8	AccelCalScore	DistributionError	TiltError	TiltRange
Float32	Float32	Float32	Float32	Float32	Float32

MagCalScore:

Represents the over-riding indicator of the quality of the magnetometer calibration. Acceptable scores will be ≤1 for full range calibration, ≤2 for other methods. Note that it is possible to get acceptable scores for DistributionError and TiltError and still have a rather high MagCalScore value. The most likely reason for this is the Trax is close to a source of local magnetic distortion that is not fixed with respect to the device.

Bytes 5-8:

Reserved for PNI use.

AccelCalScore:

Represents the over-riding indicator of the quality of the accelerometer calibration. An acceptable score is ≤1.

DistributionError:

Indicates if the distribution of sample points is good, with an emphasis on the heading distribution. The score should be 0. Significant clumping or a lack of sample points in a particular section can result in a poor score.

TiltError:

Indicates if the Trax experienced sufficient tilt during the calibration, taking into account the calibration method. The score should be 0**.**

TiltRange:

This reports the larger of either half the full pitch range or half the full roll range of sample points. For example, if the device is pitched +10° to -20º, and rolled +25º to -15º, the TiltRange value would be 20º (as derived from [+25º - {-15º}]/2). For Full Range Calibration and Hard Iron Only Calibration, this should be ≥45°. For 2D Calibration, ideally this should be ≈2°. For Limited Tilt Range Calibration the value should be as large a possible given the user's constraints.

7.6.4 Factory Calibration

kSetFactoryMagCoeff (frame ID 29 $_d$)

This frame clears the magnetometer calibration coefficients and loads the original factory-generated coefficients. The frame has no payload. This frame must be followed by the kSave frame to save the change in non-volatile memory.

kSetFactoryMagCoeffDone (frame ID 30 $_d$)

This frame is the response to kFactoryMagCoeff frame. The frame has no payload.

kSetFactoryAccelCoeff (frame ID 36 $_d$)

This frame clears the accelerometer calibration coefficients and loads the original factory-generated coefficients. The frame has no payload. This frame must be followed by the kSave frame to save the change in non-volatile memory.

kSetFactoryAccelCoeffDone (frame ID 37 $_d$)

This frame is the response to kFactoryAccelCoeff frame. The frame has no payload.

7.7 Compass Mode Commands

The Trax normally operates in AHRS Mode, which uses a proprietary Kalman algorithm to fuse the inputs of its 3-axis gyroscope, 3-axis accelerometer, and 3-axis magnetometer. However, the user can place the Trax in Compass Mode, wherein it only uses the inputs from the accelerometer and magnetometer to establish heading, pitch, and roll. In this case the Trax operates very similarly to PNI's TCM electronic compass.

There are a couple of reasons it may be desirable to place the Trax in Compass Mode. As previously mentioned, it is necessary to place the Trax in Compass Mode to perform a calibration. Additionally, if a static measurement is to be made in a known clean local magnetic field, then a somewhat higher level of accuracy is achievable in Compass Mode. Also, by placing the Trax in Compass Mode it can subsequently be placed into Sleep Mode which will significantly reduce power consumption when not taking measurements.

7.7.1 Switching Functional Mode

kSetFunctionalMode (frame ID 79 $_d$)

This frame establishes whether the Trax operates in AHRS Mode or Compass Mode. The frame has a one byte payload. The payload byte is "0" to operate in Compass Mode and "1" to operate in AHRS Mode. The default is "1".

Payload
FunctionalMode
UInt8

FunctionalMode Payload Value:
"0": Compass Mode
"1": AHRS Mode (default)

Sending the kSave command after changing the mode will save the new setting in non-volatile memory.

kGetFunctionalMode (frame ID 80 $_d$)

This frame queries the Trax functional mode. The frame has no payload.

kGetFunctionalModeResp (frame ID 81 $_d$)

This is the response of kGetFunctionalMode, and it has the same payload definition as kSetFunctionalMode.

7.7.2 FIR Filters

When operating in Compass Mode, the Trax incorporates a finite impulse response (FIR) filter to provide a more stable heading reading. The number of taps (or samples) represents the amount of filtering to be performed. The number of taps directly affects the time for the initial sample reading, as all the taps must be populated before data is output. The FIR filter settings have no affect when operating in AHRS Mode.

The Trax can be configured to clear, or flush, the filters after each measurement, as discussed in Section 7.5.2. Flushing the filter clears all tap values, thus purging old data. This can be useful if a significant change in heading has occurred since the last reading, as the old heading data would be in the filter. Once the taps are cleared, it is necessary to fully repopulate the filter before data is output. For example, if 32 FIR taps is set, 32 new samples must be taken before a reading will be output. The length of the delay before outputting data is directly correlated to the number of FIR taps.

kSetFIRFilters (frame ID 12$_d$)

The payload for kSetFIRFilters is given below.

Payload						
Byte 1	Byte 2	Count N	Value 1	Value 2	Value 3	Value N
UInt8	UInt8	UInt8	ID Specific	ID Specific	ID Specific	ID Specific

Byte 1 should be set to 3 and Byte 2 should be set to 1. The third payload byte indicates the number of FIR taps to use, which can be 0 (no filtering), 4, 8, 16, or 32. This is followed by the tap values (0 to 32 total Values can be in the payload), with each Value being a Float64, and suggested values given in Table 7-6.

Table 7-6: Recommended FIR Filter Tap Values

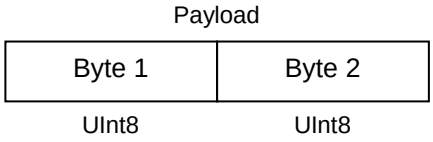
Count	4-Tap Filter	8-Tap Filter	16-Tap Filter	32-Tap Filter
1	04.6708657655334e-2	01.9875512449729e-2	07.9724971069144e-3	01.4823725958818e-3
2	04.5329134234467e-1	06.4500864832660e-2	01.2710056429342e-2	02.0737124095482e-3
3	04.5329134234467e-1	01.6637325898141e-1	02.5971390034516e-2	03.2757326624196e-3
4	04.6708657655334e-2	02.4925036373620e-1	04.6451949792704e-2	05.3097803863757e-3
5		02.4925036373620e-1	07.1024151197772e-2	08.3414139286254e-3
6		01.6637325898141e-1	09.5354386848804e-2	01.2456836057785e-2
7		06.4500864832660e-2	01.1484431942626e-1	01.7646051430536e-2
8		01.9875512449729e-2	01.2567124916369e-1	02.3794805168613e-2
9			01.2567124916369e-1	03.0686505921968e-2
10			01.1484431942626e-1	03.8014333463472e-2
11			09.5354386848804e-2	04.5402682509802e-2
12			07.1024151197772e-2	05.2436112653103e-2
13			04.6451949792704e-2	05.8693165018301e-2
14			02.5971390034516e-2	06.3781858267530e-2
15			01.2710056429342e-2	06.7373451424187e-2
16			07.9724971069144e-3	06.9231186101853e-2
17				06.9231186101853e-2
18				06.7373451424187e-2
19				06.3781858267530e-2
20				05.8693165018301e-2
21				05.2436112653103e-2
22				04.5402682509802e-2
23				03.8014333463472e-2
24				03.0686505921968e-2
25				02.3794805168613e-2
26				01.7646051430536e-2
27				01.2456836057785e-2
28				08.3414139286254e-3
29				05.3097803863757e-3
30				03.2757326624196e-3
31				02.0737124095482e-3
32				01.4823725958818e-3

kSetFIRFiltersDone (frame ID 20 $_d$)

This frame is the response to kSetFIRFilters. The frame has no payload.

kGetFIRFilters (frame ID 13$_d$)

This frame queries the FIR filter settings for the sensors. Byte 1 should be set to 3 and Byte 2 should be set to 1.



kGetFIRFiltersResp (frame ID 14$_d$)

This is the response to kGetFIRFilters and it has the same payload definition as kSetFIRFilters.

7.7.3 Power Down/Up

For certain applications it is desirable to conserve battery power. To maintain accurate heading readings in AHRS Mode generally requires continual sensor updates to the Kalman algorithm. However, this is not the case in Compass Mode wherein readings may be taken only when heading information is desired. Consequently, when in Compass Mode the Trax may be powered down when heading data is not required.

kPowerDown (frame ID 15$_d$)

This frame is used to power-down the module. The frame has no payload. The command will power down all peripherals including the sensors, microprocessor, and RS-232 driver. However, the driver chip has a feature to keep the Rx line enabled. The Trax will power up when it receives any signal on the native UART Rx line.

kPowerDownDone (frame ID 28$_d$)

This frame confirms the Trax received a command to power down. The frame has no payload.

kPowerUpDone (frame ID 23$_d$)

This frame confirms the Trax received a command to power up. (The Trax will power up when it receives any signal on the native UART Rx line.) The frame has no payload.